B-210

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

December 16, 1963

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineer

Subject: Monthly Progress Report No. 1, Project No. HPS - 1 (60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 November 1963 through 30 November 1963.

Gentlemen:

Project activities during November have consisted of:

1. Continued testing of paints on the accelerated wear machine.
2. Development of a small "Special Reflectance Head" for use in evaluating bead retention of the beaded stripes on the accelerated wear machine.
3. Further work on a special report on highway test results.

Beading makes a very significant contribution to paint durability. Also, we have observed that most authorities consider that night visibility is the most important single property of a traffic paint. For these reasons it was concluded that a capability for evaluating beaded systems would be a necessary adjunct of the laboratory accelerated wear test. Toward this end, each paint is now being tested on the machine both with and without beads.

No existing device was capable of measuring bead retention or night visibility on the small test areas of our disc surface. Accordingly, a suitable device has been constructed by modifying the sensing head of a Photovolt Reflectometer. Some of the precise geometrical similitude of the Hunter device has been sacrificed; however, meaningful correlation has been achieved that permits one to rank tests for this critically important property.

Paint No. 15 (straight alkyd) and Paint No. 16 (alkyd-chlorinated rubber) in the original highway tests are still displaying outstanding performance;

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therefore, the special report on these systems is being deferred so as to include photographs at eighteen months.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

January 10, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineer

Subject: Monthly Progress Report No. 2, Project No. HPS - 1 (60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 December 1963 through 31 December 1963.

Gentlemen:

During the month of December project work was concentrated exclusively on testing activities with the accelerated wear machine utilizing adjoining beaded and unbeaded stripes of test paints on the ground concrete substrate. In addition to visual observations of film integrity, the new special reflectance head was used for routine recordings of night visibility on test stripes.

This work has further documented the dominant role of beading not only for night visibility but also for paint durability. It now appears obvious that beading must be considered as an integral part of the paint formulation. All work to date has been performed with "bead on" formulations. Plans were made to begin immediately experimental studies of "bead on" versus "bead in" formulations at several different beading concentrations.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

REVIEW
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FORMAT 1-21 1964 BY

B-210

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

February 6, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineer

Subject: Monthly Progress Report No. 3, Project No. HPS - 1 (60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 January 1964 through 31 January 1964.

Gentlemen:

Project activities in January have consisted of:

1. Preparation of Quarterly Progress Report No. 1 to be submitted about February 10, 1964.

2. Experimentation of laboratory application techniques for hot melt compositions.

3. Continuation of test runs on laboratory wear tester and modification of machine to increase wheel velocity.

4. Planning of a designed experiment to evaluate the variables of pigment volume concentration, bead loading, and film thickness by analysis of variance utilizing the accelerated wear tester with a standard alkyd type formulation.

During February the following activities are anticipated:

1. Preparation of Special Highway Test Report.

2. Preparation of Project Continuation Proposal.

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3. Further correlation test runs on wear tester.

4. Initiation of experimental runs of designed experiment of item 4 above.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

F. Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

March 4, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 4, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 February 1964 through 29 February 1964.

Gentlemen:

February project activities have consisted of:

1. Further modification of laboratory wear tester. The increased wheel velocity adopted last month was found to greatly increase the tendency of the abrading wheel to bounce and develop flat spots. This reduced the life of the rubber tire, and appeared to be a potential source of erratic test performance. The problem was solved by attaching a shock absorber to the driving wheel carriage.

2. Completion of laboratory wear testing of a set of "bead-on" paints. Preliminary results of this study were given in Quarterly Report No. 9 (2/3/64) and further details will be reported subsequently.

3. Initiation of designed experiment for a "beads-in" paint to evaluate by analysis of variance the variables of pigment volume concentration, bead loading and film thickness, with a standard alkyd formulation, and utilizing the laboratory wear tester.

4. Preparation of Project Continuation Proposal.

5. Highway test observations of Series I and II.

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6. Some preliminary work aimed at enhancement of "wet visibility" of traffic paints.

During March the following activities are anticipated:

1. Preparation of Special Highway Test Report.

2. Preparation of Hot Melt Proposal.

3. Evaluation of a "wet visibility" concept.

4. Completion of current test series on laboratory wear tester, data analysis and report.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

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B-210

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

April 6, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. E. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 5, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 March 1964 through 31 March 1964

Gentlemen:

March project activities have consisted of:

1. Analysis of sources of variation in laboratory wear tester operation. Alignment of the driving wheel has been observed to be a very critical operating variable. A slight modification in the wheel suspension has been designed to provide self-alignment of the driving wheel.

2. Continuation of "beads-in" study on laboratory wear tester. This study is about one-half completed. Very marked potentials for durability improvement are already clearly evident.

3. Series I Special Highway Test Report. The draft of this report is nearing completion.

4. Hot Melt Proposal. The draft has been completed.

5. Wet Visibility Concept. Prototype bodies have been case for preliminary experiments.

Anticipated April Activities:

1. Installation of self-alignment modification of machine.
2. Completion of "beads-in" study.
3. Technical-legal analysis of "beads-in" patents.

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4. Completion of Series I Special Highway Test Report.
5. Further work on wet visibility concept.
6. Initiation of epoxy ester vehicle synthesis.

Respectfully submitted:

[redacted]
W. H. Burrows
Project Director

Approved: [redacted]

Dr. F. Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

May 7, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 6, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 April 1964 through 30 April 1964.

Gentlemen:

April project activities have consisted of:

1. Installation of drive wheel self-alignment modification of accelerated wear tester. It had become evident that various necessary adjustments of the wheel carriage had caused changes in alignment of the drive wheel. Except for observation of changes in the wear pattern over a long period, there was no way to accurately assess "trueness" of wheel alignment with adequate precision. To correct this shortcoming, a "floating" bearing suspension was designed and installed on the idler shaft to provide self-alignment of the drive wheel to a "true" position. This has completely eliminated the possibility of development of lateral thrusts and resultant excessive drag on the drive wheel.

2. New abrasion wheel. Recent work with beaded paints has required substantially longer tests than in previous work and tread wear has become excessive. In some cases one test has completely worn out the special abrasive rubber ring. Furthermore, there are indications that rings may vary in their condition of cure. In view of these difficulties, a decision was made to experiment with rings prepared from tire tread stock. A new wheel has been designed to accomodate removable aluminum rings onto which tread stock of any desired type can be vulcanized. This system is ready for evaluation as soon as the current test series is completed.

3. Continuation of beads-in study. This study was continued throughout the month except for a two weeks delay occasioned by late delivery of an order of abrasive rings. The runs are now expected to be complete before May 8. The performance potential for certain "beads-in" compositions continues to look very favorable.

4. Technical-legal analysis of "beads-in" patents. Actual analysis work has been held in abeyance pending collection of additional items of technical information.

5. Series I Special Highway Test Report. The draft of this report was completed, and it is now undergoing editing.

6. Wet visibility concept. Experimentation with means of adhering beads to special shapes has not yet achieved adequate results to permit any evaluation work.

7. Epoxy ester synthesis. This work had been temporarily deferred, but was initiated during the last week of April. The first synthesis appears to have provided a vehicle approaching the properties that are believed to be desired.

8. Infra-red work. Spectra have been run on the various vehicles of interest to the test program.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

F. Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

June 5, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 7, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 May 1964 through 31 May 1964.

Gentlemen:

Project activities for the subject period have consisted of:

1. New Abrasion Wheel. The special abrasive rubber rings which have been used on the wear test machine since its initial construction have become inadequate because of excessively rapid and non-uniform wear. To correct these shortcomings, a new drive wheel assembly, designed to accomodate tires molded of commercial tread stock, was installed and operated. However, the tire tread, even when cured well beyond conventional levels, develops a tacky surface and transfers black gum to the test disc when operated on the accelerated wear tester. When a small amount of fine sand is distributed to the disc, the tread rubber rapidly assumes a conventional appearance and the tackiness disappears. It is apparent, therefore, that "road dust" must be supplied to the disc if realistic operation is to be attained utilizing a tread stock abrading wheel.

The tread stock appears to be more wear resistant than the special abrasive rubber rings and should be capable of yielding distinctly superior wear uniformity on the test discs if controlled distribution of abrasive to the disc were provided. Furthermore, the simulation capability of the machine would be further enhanced by addition of two independent variables -- abrasive quality and quantity. By now, the addition of variables should perhaps be regarded as a mixed blessing, but the necessity of this change seemed obvious; therefore, a device for controlled application of abrasive was designed, and fabrication and installation is now nearing completion. In essence, this solenoid operated metering device, controlled by a recycling timer, will periodically discharge uniform small batches of abrasive to the disc. It is believed that this is a final modification of the accelerated wear tester.

2. "Beads-in" Study. This series of tests was completed in May. The unusual wear resistance of certain beads-in combinations was a major factor in directing the decision to investigate a tread stock tire for the accelerated wear tester. Details of the analysis-of-variance study will be deferred for a special report. Briefly, it has been found that maximum durability occurs at the highest beading level investigated (above all specification levels), and with the paint at a P.V.C. (pigment volume concentration) somewhat below conventional levels.

3. "Beads-in" Patents. A part of the patent art has been reviewed, but discussion with patent counsel has been deferred pending a more thorough study.

4. Series I Special Highway Test Report. Editing of the final draft is nearing completion.

5. Wet Visibility Concept. A larger supply of the special clay shapes was fired for beading experiments.

6. Epoxy Ester Synthesis. The vehicle prepared last month was formulated into a paint and applied to wear test discs. Testing awaits completion of current modifications of the accelerated wear tester.

Future Plans

In addition to continuation of the work described above, a study of flexibility (conical mandrel) and abrasion resistance (falling sand) of standard test paints is to be initiated.

Preparations for a new set of highway tests to include "beads-in" concepts and two-coat applications will be undertaken. It is also hoped that at least one new vehicle material (probably the synthesized epoxy ester) will be a candidate for these tests.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Dr. Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

July 8, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. E. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 8, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 June through 30 June, 1964.

Gentlemen:

Project activities for the subject period have consisted of:

1. New Abrasion Wheel. The basis for a decision to utilize a tire tread stock abrasion wheel together with metered abrasive media was reported last month (Monthly Progress Report No. 7). Much mechanical experimentation was required to develop a suitable metering device for the fine sand abrasive. The final design consists of a transparent cylindrical sand reservoir which supplies sand to a small glass tube having a constriction, thence to a rubber tubular section which functions as a pinch valve to interrupt sand delivery, and finally through a copper delivery tube to the disc surface. The pinch valving operation is actuated by a solenoid and controlled by a timing device.

Satisfactory precision and reliability of this device has been established and experimentation is now in progress to determine the most appropriate timing cycle (controlling the quantity of abrasive consumed) to attain desired wear rates.

It has been observed in the course of the foregoing experimentation that the new tread stock wheels are wearing at an extremely slow rate as compared with the special eraser stock treads previously used. The problem of excessive tread wear appears to have been resolved.

2. Epoxy Ester Traffic Paint. A paint formulated from the laboratory synthesized epoxy ester vehicle was found to possess approximately the same flexibility in a bending test as the standard alkyd paint (No. 15). For this test, paint films of 5 mils wet film thickness were applied to 20 gauge steel panels and air dried overnight. The panels were then baked for 24 hours at 80° C, cooled to room temperature and bent over a conical mandrel. Although the epoxy film was observed to be somewhat harder, no difference was found in

the flexibility of the two paints. Wear test disks have been prepared with these paints and are currently being tested on the accelerated wear machine.

3. Wet Visibility Concept. Several attempts to bead the special shapes did not prove adequate.

4. Special Highway Test Report, Series I. Editorial work was continued.

5. Technical Conference. During a vacation tour Mr. W. R. Tooke, Jr. called on Mr. Herbert L. Rooney of the California Division of Highways in Sacramento. It was most encouraging to learn that California is observing very good performance with certain experimental paints based on epoxy ester vehicles. Much interesting information was obtained on various devices for improving night visibility. The extensive use by this organization of physical analytical methods, particularly infra-red, x-ray and gas chromatography was most impressive.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

F. Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

August 5, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 9, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 July through 31 July 1964.

Gentlemen:

July project activities have consisted of:

1. Accelerated Wear Testing. In preparation for a final series of highway tests, a screening of candidate systems was conducted on the accelerated wear tester. With the possible exception of a proposed two coat technique which yielded disappointing results, all candidate systems appeared to justify inclusion in the field tests. It was decided that the two coat technique should also be included in the field tests because of the novelty of this concept.

Other experiments aimed at correlation of the accelerated wear test with prior field tests were conducted. These experiments have indicated that the new abrasion wheel yields much less disc to disc variations than the old abrasive rings. Unfortunately, however, the character of the wear appears to have been altered, and unbeaded paints have been observed to exhibit superior wear to the same paints beaded. Changes in wheel loading and abrasive charging are being explored to attempt to achieve better correlation with field experience.

2. Preparations for Highway Tests. Several minor modifications were made on the highway stripe applicator to improve its performance. The test series has been planned and paints prepared to include: (1) "Beads in" versus "beads on" comparison, (2) one versus two coat application, (3) epoxy ester vehicle study, (4) moisture cured urethane vehicle study.

3. <u>Other Activities</u>. Other project activities were subordinated to the above-described work during July. Further analysis of a "beads in" study has been made, and editorial work on a special report has continued.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

September 10, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 10, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 August thru 31 August 1964.

Gentlemen:

August project activities have consisted of:

1. Accelerated Wear Testing. Experimentation with machine operating conditions (wearing wheel loadings and abrasive application rates) was continued. Unexpectedly poor test performance of some "beads-on" paints required further investigation. From a careful inspection of the surfaces of these beaded samples on test discs, it was determined that the laboratory bead-on technique was very unrepresentative. The laboratory practice of applying an excess of beads, and dusting off the loose beads after the paint dries was seen to yield surface characteristics entirely different from those produced by properly proportioned bead application. A simple bead distributor was constructed to provide the required proportioning onto test panels. This device performed very satisfactorily during panel preparation work. Wear testing of panels prepared in this manner is in progress.

2. Preparations for Highway Tests. Final plans for Highway Tests, Series III were completed. The highway stripe applicator was modified to handle "beads-in" formulations, and calibrated for appropriate volumetric application.

3. "Beads-in" Patent Study. The patent art on "beads-in" paints has been reviewed. In particular, U. S. 2,574,971 (1951) and U. S. 2,574,972 (1951) claim compositions encompassing a very broad range of practical formulations. The file on these patents has been requested from the Patent

Office to determine if litigation has occurred. Unless these patents have been found invalid by court decisions, the proprietary rights of the owners to the compositions claimed must be presumed valid. This study will be concluded with a brief report as soon as the requested files have been reviewed.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

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ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

October 9, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 11,
Quarterly Progress Report No. 12
Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 September 1964 through 31 September 1964.

Gentlemen:

Project activities for July, August, and September were conducted in the following areas:

1. Accelerated Wear Testing

2. Highway Tests

3. Night Visibility Media

4. Other Activities

A discussion of these activities follows:

I. Accelerated Wear Testing

A. Test Machine Studies

Quarterly Progress Report No. 11 reported the installation of a sand metering device in an effort to eliminate transference of heavy black marks from tread stock tires to paints on the concrete test disc. After a period of operation with this sanding device it became evident that black marks would still hamper the tests. Experimentation with another type of black tread stock yielded less tread wear, but insufficient reduction in the black marking. A special white tread stock was investigated. This material produced no marks, but its wear was non-uniform and rapid. This test situation was considered unsatisfactory.

Up to this time the tester had been operated on a cycle of 59 minutes dry, 1 minute wetted. It was suspected that the marking from black treads would not occur on a wetted surface. This was confirmed by experimentation on a continuously wetted disc. This experiment also reconfirmed the occurrence of greatly increased wear rates on wet surfaces. Further, it was found that a cycle consisting of 45 minutes of wetting followed by a 15 minute drying period (paint fully dried) did not exhibit the tire marking effect.

It will be seen that these results forced a reappraisal of the testing rationale. Other investigators have found that laboratory wet abrasion tests provide better correlation with highway results than any other uniform test condition. Unquestionably, however, wetting-drying-heating-cooling changes affect adhesion of paint films to concrete, and cannot be ignored in a comprehensive accelerated test. If changes during long continuous dry periods on a highway can be regarded as relatively slight, then why attempt to simulate these periods in an accelerated test? Rather, may we not seek to attain in the laboratory test a balance between total time of wet abrasion and wetting-drying-heating-cooling cycles which most nearly simulates the balance of these factors as they occur in the field?

With these considerations in mind, the wetting-drying-heating-cooling was altered to a 30 minute environmental cycle of 20 minutes wetting-cooling and 10 minutes drying-heating in order to gain further acceleration of this environmental factor. Even so, when the machine was operated with minimum wheel loading, abrasion effects were so rapid that only about 5 environmental cycles could be completed before the paint was worn through by abrasion.

It was believed that the machine must have the capability to fully control the relative intensity of these paint deterioration factors. Since varying wheel loadings could not accomplish this objective, it appeared necessary to modify the machine to vary wheel velocity. A suitable variable speed drive for this purpose will be installed as soon as possible.

It is proposed that future work with the wear tester shall encompass conditions and effects ranging as follows:

1. Continuous wet abrasion, high speed - abrasion factor only.
2. Environmental cycling, several intermediate speeds - combined factors.
3. Environmental cycling, lowest speed - environmental factor dominant.

By establishing the responses of standard paint systems to this range of conditions, the capabilities of the tester for correlation with various field conditions will be defined.

B. Test Panel Preparation on Concrete Discs

Significant improvements in uniformity of paint application to test discs have been achieved by utilizing single metal templates cut to the complete disc application pattern. The templates, of selected thicknesses, effectively control paint drawdown thicknesses and spacing on the discs.

As reported in Monthly Progress Report No. 10 (9/9/64), a simple bead distributor has been developed which applies beads to the small test paint sections on the disc to quantitatively simulate field applications. The distributor has been calibrated so that any desired level of beading concentration can be attained. A number of paint specimens on discs have been prepared at a loading of 6 lbs of beads per gallon. Excellent bead distribution was observed on these panels.

II. Highway Tests

On September 2, 1964 application of a cross-stripe test series was initiated on the Atlanta Northeast Expressway. A mechanical failure of the application equipment forced abandonment of the application at that time. It was also disclosed that the spray equipment would not handle the experimental pre-mixed beaded paints with adequate reliability (stopages). These paints are being reformulated with a much finer gradation of beads and somewhat lower beading concentration as dictated by equipment limitations. This application is to be rescheduled as soon as feasible.

III. Night Visibility Media

Beading was applied to the previously prepared special small shapes in a quantity sufficient to permit a bench scale evaluation of performance. The highway viewing geometry is being approximated at about 1/10 scale to permit direct comparisons of regular beaded paint with media-treated paint under wet and dry conditions. It is not anticipated that the crudely prepared media will approach its full capabilities, but the relative wet and dry reflective intensities should provide an indication of the practical potential of the concept. The setup for these tests is essentially complete except for final precise illumination and viewing (photographic) positionings.

IV. Other Activities

A review of "beads-in" patent art was completed. Further revisions have been made in technical reports being drafted. Increased attention is being directed to statistical design and analysis of experiments.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

F. Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

November 9, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No.12, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the Period 1 October through 31 October, 1964.

Gentlemen:

October project activities have consisted of:

1. Accelerated Wear Testing. A variable speed drive was installed on the testing machine, and a series of tests have been completed to explore the effect of the speed variable, as discussed in the previous report (Monthly Progress Report No. 11, October 9, 1964).

Operated at the higher speeds, the device produces an abrasive-erosive mode of failure. At the lower speeds, failure follows a cracking-adhesion mode. In view of these differing time scales, we now question the merit of attempting to reproduce particular field conditions in the laboratory test. Rather, it appears more feasible to evaluate the relative resistance of paints to the two principal modes of failure.

Previous efforts to correlate laboratory results with field results have been unsatisfactory, largely because of discrepancies in the physical conditions of the two test systems. It is believed, however, that a simple mathematical model, utilizing the results of these two failure tests, might provide an estimation of field performance over a broad range of environmental conditions.

2. Highway Tests. All difficulties with materials and equipment have been corrected and application of Series III is scheduled for November 12.

3. Night Visibility. A bench-scale test of relative wet and dry night visibility performance of a conventional beaded paint versus a special granule-treated paint disclosed a highly significant enhancement of night visibility of the water wetted paint bearing the granule treatment. Water films of about 1/8 inch in thickness were observed to render a beaded paint film almost totally invisible, while a granule-treated paint film was only slightly reduced in brightness. A special report has been prepared covering this investigation, and a record of invention has been filed. A patent novelty search has been requested to supplement recommendations

for further development work.

4. Other Activities. Systematic paint formulation and paint vehicle studies have continued to be subordinated to the primary problem of the accelerated wear test. This test is now believed to be adequate for formulation evaluation, and this subject will receive increasing attention. Project personnel have also maintained close liaison with the Highway Department Laboratory, and this has resulted in increased appreciation of some of the practical use problems which relate to paint specification development.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

December 4, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 13, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 November through 30 November 1964.

Gentlemen:

November project activities have consisted of:

1. Accelerated Wear Testing. The tester has been in operation nearly continually during the current month. Three types of test cycles have been adopted as standards: (1) High speed continuous wet. This test produces rapid erosive failure of paint films. (2) Medium speed wetting-drying. This test yields erosive failure at a rate that permits bead retention to be followed progressively. (3) Slow speed wetting-drying (no abrasive). This test displays cracking, spalling, and chipping modes of failure with some paints.

Standard formulations are being processed through these tests with extensive replications, beaded and unbeaded, at several film thicknesses. Even the slow speed test has not appeared to produce the degree of chipping that has been observed on the highway. Apparently our test panels provide a much better surface for paint adhesion than typical highway surfaces. Accordingly, we have treated some panels with lubricating oil to simulate highway surface contamination. No test results are available at this time, but further experimentation has been projected along these lines with varying amounts and type of contamination. Every effort is being made to expedite accumulation of test data to support a comprehensive technical report on the accelerated wear tester.

2. Highway Tests. The highway test applications, Series III, were completed on November 12. The work proceeded this time without difficulty with materials or equipment. The bead-in paints were not noticeably different in application properties from regular paints. Some slight smearing of our epoxy ester formulation was observed when traffic was released; however, if this item should display special merit, the set time can be accelerated.

3. Night Visibility. Research experiments were completed on this special study last month. The report should be transmitted early in December. Results of a patent novelty search are expected momentarily (according to our patent attorney). Further development work on this subject has been suspended pending advice from the project sponsor.

4. Other Activities. On November 24 project personnel participated in a meeting of technical personnel of the Georgia Highway Department and of manufacturers of traffic paints to discuss specifications. The attached data tabulations and plots were prepared to provide formulation background for the discussion. The paint manufacturers did not express any fundamental objections to the specifications; however, it was evident that the present minimum level of vehicle solids encourages the use of quantities of bodying agents which may adversely affect vehicle stability. A suggestion that the minimum vehicle solids level should be raised appeared to be most constructive. A suggestion that consistency minimum should be 70 KU was recognized to be in line with Federal Specification TT-P-00115b, but not necessarily consonant with Georgia needs. A suggestion that Class B diatomaceous silica be specified in place of Class A was also agreed to merit further study. Project personnel are continuing to work with the Highway Laboratory in studying possible constructive revisions of specifications.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

F. Bellinger, Chief
Chemical Sciences and Materials Division

encl.

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
Project B-210

CONSISTENCY STUDY OF TENTATIVE MAINTENANCE SPECIFICATION NO. 4 (WHITE) AND NO. 5 (YELLOW) FOR TRAFFIC LINE PAINT

	White Paints (#4)						Yellow Paints (#5)					
Paint Identification	WA	WB	WC	WD	WE	WF	YA	YB	YC	YD	YE	YF
Paint Composition (Wt. %):												
Composite Pigment*	47	47	47	50	50	50	47	47	47	50	50	50
Total Vehicle	53	53	53	50	50	50	53	53	53	50	50	50
Vehicle Solids (Wt. % of vehicle)	39	43	47	39	43	47	39	43	47	39	43	47
Paint Properties:												
Consistency, K.U.	68	85	105	71	89	115	69	87	109	74	94	123
Wt/gal., lbs.	10.8	10.8	10.9	11.1	11.2	11.2	11.0	11.1	11.2	11.4	11.5	11.6

*Composite Pigment

Percent by Weight

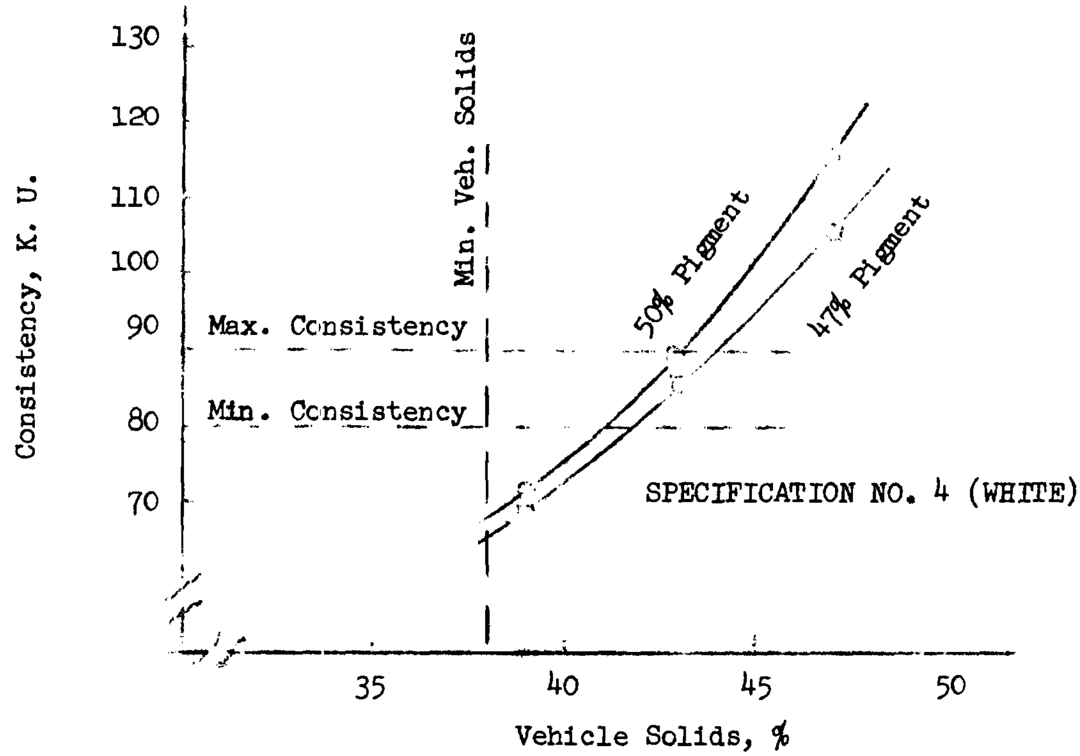
	White	Yellow
TiO_2	28.0	-
Chrome Yellow	-	35.0
Calcium Carbonate	30.0	20.0
Dia. Silica	20.9	20.0
Mg Silicate	21.0	25.0
Al Stearate	0.1	-

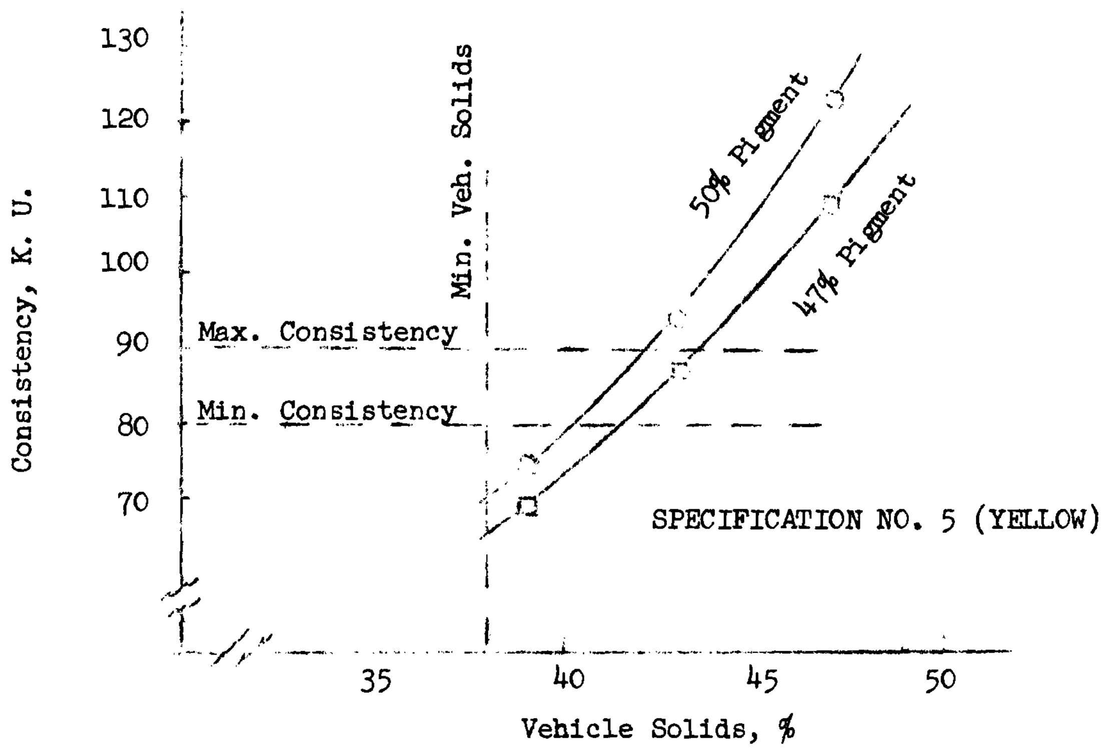
Procedure

Mill base dispersions of white and yellow paint were prepared and let down as required to yeild the paint compositions and vehicle solids indicated in the formulations above. After 24 hours, consistency and weight per gallon were determined.

Georgia Institute of Technology
Engineering Experiment Station
Project No. B-210

CONSISTENCY OF PAINTS AS A FUNCTION OF
VEHICLE SOLIDS AND PIGMENTATION





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State Highway Department of Ge
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. H. H. Huckeba
State Highway Plannir

Subject: Monthly Progress Repo
Quarterly Progress Report No. 13
Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 October 1964 through 31 December 1964

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Gentlemen:

Project activities have included the following topics: (1) accelerated wear testing, (2) highway tests, (3) night visibility media, and (4) other activities. A discussion of each of these activities follows:

I. Accelerated Wear Testing

During the subject period, wear testing has been confined to three selected machine operating conditions as described below:

	Operating Conditions		
	I	II	III
Wheel Speed, RPM	100	40	10
Wheel Load, lbs.	40	40	40
Water Cycle:			
On, min.	Continuous	20	5
Off, min.	-	10	25
Abrasive Feed, g/hr.	17	17	none

Condition I produces very rapid erosive wear of traffic paint films so that a typical test is completed in about 2-3 hours. Because of the continuous wet condition, and because of the very rapid erosion, it is not feasible to observe bead retention with this test.

Condition II yields erosive film failure similar to that of Condition I, but over a longer time period. The wetting-drying cycling provides dry periods for checking bead retention by reflectance. When the essential equivalence of the tests became apparent, Condition II was selected as the more useful test. A typical plot of integrity versus test time is shown in Figure 1.

REVIEW
PATENT 2-4 1965 BY
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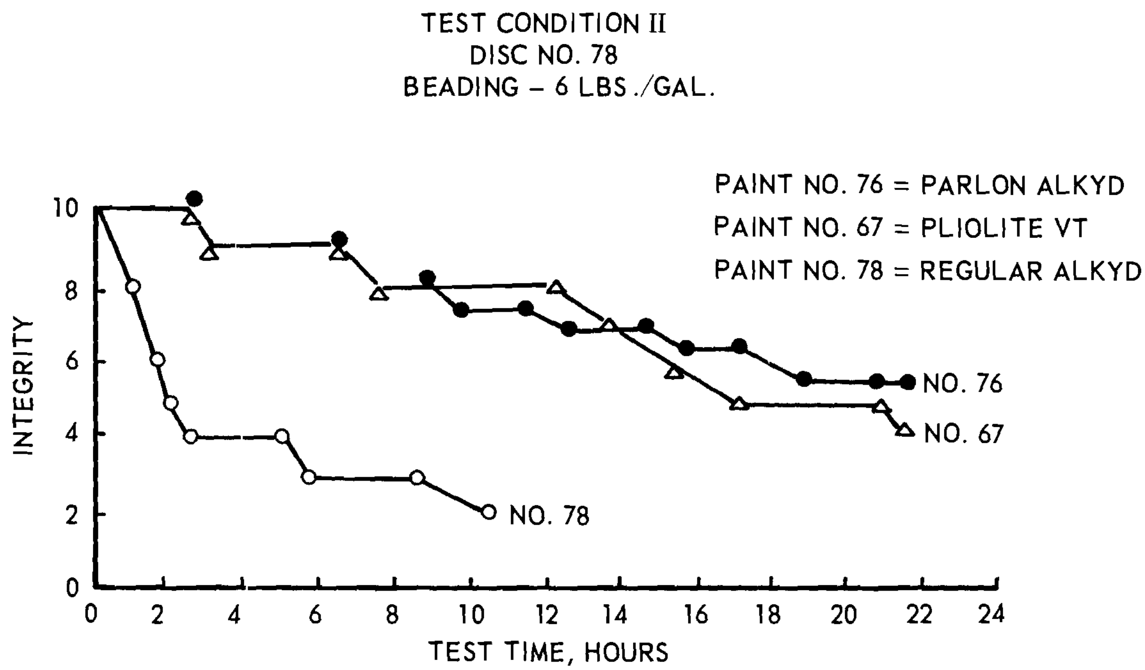

Figure 1. Accelerated Wear Test Results.

Condition III is a much slower test. Testing periods of 200 hours have not yielded failures with some paints. Failure of paints on this test is associated with cracking, spalling, chipping, or peeling, rather than erosion. During the longer dry cycle periods of this test, the abrasion wheel develops a slight tack which imparts a distinct shearing and lifting force to the paint film. By the elimination of abrasive and reduction of wheel speed to a practical minimum, it was possible to sufficiently retard the erosive effects that these other modes of film failure could be observed. A specimen of data obtained from a Condition III test run is given in Table I.

Test work is being continued at full capacity on the accelerated wear tester to accumulate adequate data to fully define the capabilities of the test methods. However, it is necessary now to recognize that the accelerated wear tests are not fully correlating with current highway tests. At the same time, it is believed that an understanding of the nature of the differences has been gained, and an improved conception of the physical requirements for traffic paints has been realized. These ideas will be developed more clearly in the light of current highway test observations as described below.

II. Highway Tests, Series III.

This series of highway tests was placed on the Atlanta Northeast Expressway (I-85) in the outer northbound lane about 1/4 mile north of the Piedmont Road exit on November 12, 1964. The tests involved four different paint types at three wet film thicknesses (10, 15,20 mils) beaded and unbeaded. In addition, these paints were formulated with "beads in" at 45% BVC and tested at 20 and 30 mils wet thicknesses both with and without drop-on beading. Finally, a single stripe was placed as a two-coat application of #90 alkyd. Both coats were beaded normally, the second coat applied 20 minutes following the first. Test results at one month are presented in Table II. Because of the immaturity of these tests, a detailed discussion is not justified at this time; however, wear has already progressed sufficiently to justify some significant observations.

Wear has been very rapid for this series -- at least as rapid as Series II. Film failure is by chipping in almost all cases. #86 Pliolite is the exception which shows almost no chipping. Beads-on films are invariably superior to unbeaded films in integrity, but the effect of increasing film thickness is not so marked. Beads-in formulations have not yet displayed any distinct superiority to the same formulations without such beading. Most significantly, while the #90 alkyd has exhibited some chipping failure, its performance is generally comparable to the other paints in this series, and certainly does not show the distinct inferiority displayed in recent accelerated wear tests.

These observations have stimulated further efforts to rationalize mechanisms of film failure. Among the three series of highway studies that have been conducted, the results have shown a progressive shortening of film durability and a

TABLE I

TEST RUN OF CONDITION III

Test Time (hrs)	Paint No. and Type	Observations, Disc No. 77
1	78 Alkyd	Beaded and Unbeaded - Rapid development of heavy smear effect.
4	76 Parlon Alkyd	Unbeaded - Very fine hairline cracks
22	76 Parlon Alkyd	Unbeaded - Substantial cracks
72	67 Pliolite VT	Beaded - Very fine hairline cracks
211*	76 Parlon Alkyd	Beaded and Unbeaded - Heavy spalling, moderate chipping.
	67 Pliolite VT	Beaded and Unbeaded - Light cracks

*Test terminated at 211 hrs.

TABLE II

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
ONE MONTH OBSERVATIONS

(Beaded-Unbeaded)	Reg Alkyd B	Reg Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
				Integrity*					
Paint No.	90	90	88	88	84	84	86**	86**	90
0% BVC									
10 mils	7	4	8	7	7	6	6	7	
15 mils	9	4	9	6	9	8	7	9	8
20 mils	8	5	9	7	10	8	9	9	
Paint No.	91	91	89	89	85	85	87**	87**	
45% BVC:									
20 mils	8	7	9	8	7	8	7	8	
30 mils	9	7	7**	7**	10	9	8	8	
				Hunter Night Visibility					
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC:									
10 mils	26	3	40	4	13	3	20	3	
15 mils	25	2	30	4	45	2.5	18	35	22
20 mils	36	3	19	2	40	4	10	4	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC:									
20 mils	20	6	20	8	18	5	15	14	
30 mils	30	12	12	9	35	3	18	14	
				Special Reflectance					
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC:									
10 mils	10	10	13	9	9	7	13	9	
15 mils	17	4	15	9	18	9	11	8	18
20 mils	26	5	26	9	18	8	11	9	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC:									
20 mils	13	10	12	9	12	11	10	10	
30 mils	16	11	12	9	15	11	11	10	

* Integrity determinations were based on chipping with exceptions noted.

** These paints showed integrity failure by erosion or smearing rather than chipping.

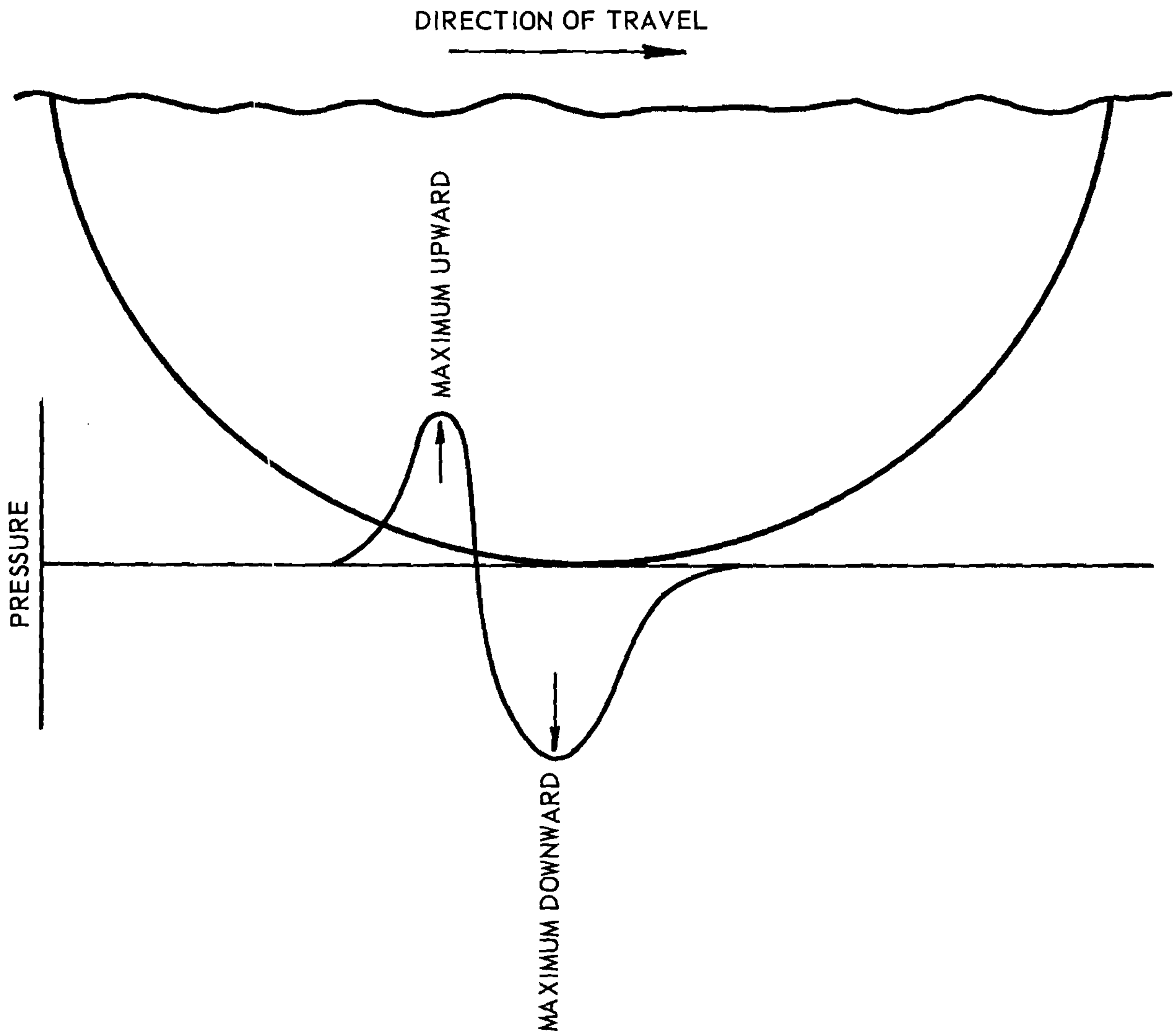

Figure 2. Pressure Distribution Under a Moving Tire.

trend to failure by chipping rather than abrasion. Despite the numerous possible sources of variation in results, it is believed that the primary variable is the condition of the concrete highway surface. The highway surface apparently has become increasingly contaminated during the three year period, and perhaps the locations of Series II and III were in areas of higher initial contamination. In any case, when a good quality traffic paint exhibits chipping failure after one month's field exposure, it is almost certain that initial adhesion was inadequate and the failure was induced almost entirely by mechanical stresses imparted by tire action.

How, specifically, does tire action impart stresses affecting adhesion? Qualitatively, when a tire rolls over a painted surface it imparts first a downward pressure on the film immediately followed by a release of pressure and finally an area of low pressure (vacuum) along the parting line of the paint-tread interface. At high speeds this vacuum might approach a full atmosphere, and rapid air expansion under the film could have an explosive upward pressure effect. Under wet conditions, the tire-paint parting would involve the splitting of a water film, and the upward tensile force on the paint film required to induce this splitting would not be limited to one atmosphere of pressure. It will now be evident that the pressure on a paint film under a moving tire will be distributed as shown in Figure 2. It is certainly not difficult to imagine that a progression of these pressure waves over a paint film could finally induce loss of adhesion.

To what extent may one relate this theory to observed paint performance? First, the importance of adhesion to traffic paint durability is further emphasized in terms of applied forces which can destroy the bond. A general experimental observation that hard films are more susceptable to chipping failure than softer films is consistent with the conception that pressure waves would induce greater stress concentrations in non-compliant rigid films so that much greater adhesion might be required to prevent chipping failure. Field results suggest that, in general, the necessary superior adhesion has not been realized.

Second, the theory provides a mechanism to explain the relatively rapid flaking of Series II and III Highway Tests if one assumes poorer initial adhesion for these tests. Finally, the source of correlation difficulties between the highway tests and the laboratory wear tester now seem apparent. A means must be found to gain an improved simulation of the pressure wave effect on the wear tester if correlation is to be improved.

A more detailed study of the pressure wave theory and its relation to the wear tester and to the physical property requirements of traffic paints is being made. From an improved understanding of the pertinent surface dynamics, the design and testing of traffic paints for heavy service conditions may ultimately be based on a sound theoretical model rather than on naive empirical simulations.

III. Night Visibility

A special report was issued in December describing activities in this area through the month of November 1964. This report describes a novel retroreflective granule for use in traffic markings. This granule, which may be of tetrahedral or other suitable shape, elevates the retroreflective medium (glass beads) in such manner as to overcome the obliterating effect of water films encountered in wet weather. Photographs included in the report illustrate the high contrast in visibility obtainable with this material, as opposed to conventional reflective media.

A survey of the patent literature disclosed a prior art consisting of the following patents: Palmquist #2,294,930; Weber #2,345,644; Flood #2,355,430; Palmquist et al #2,407,680; Wynn #2,865,266; and Palmquist et al #3,043,196. Only Flood, Wynn and Palmquist (3,043,196) show the use of non-spherical granules in traffic marking paint. Flood and Wynn are confined to specularly reflecting or diffusing granules (crystal faces), while Palmquist discloses granules of irregular shape coated with glass beads. The last quoted reference would, therefore, seem to offer the only interference with the idea incorporated in Tooke's report.

Since the fundamental conception is anticipated in the patent literature, it has appeared appropriate to curtail the developmental work suggested in the report and confine further investigations to selected field evaluations. Some additional funding may be required to conduct these evaluations, and a proposal for this work is being prepared.

IV. Other Activities

An investigation of certain formulation details of the Georgia Specification Traffic Paints was discussed in Monthly Progress Report No. 13. This work was concerned primarily with the relations of vehicle solids with paint consistency and appropriate specification limits. The findings indicated that a slight increase in the specified minimum vehicle solids would be justified.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

February 8, 1965

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 15
Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 January 1965 through 31 January 1965

Gentlemen:

Project activities have continued in the following areas:

1. Accelerated Wear Testing. In the previous report data was presented to show that the regular alkyd loses integrity much more rapidly than the other paints under the test conditions described. On the other hand, highway test data showed that the alkyd was very competitive in performance with the other test paints. The lack of correlation was too large to be ignored. The alkyd is unquestionably softer than the other test paints, but the relative softness does not adversely affect its highway performance. On the accelerated wear tester, however, the alkyd was seen to deteriorate rapidly with a crushing and slight smearing effect. Although the wheel loading of 40 pounds was selected to simulate realistic surface pressures, the tester apparently imparts greatly exaggerated shearing stresses to a paint film as compared with highway conditions where pressure effects predominate.

It has now become obvious that the tester is inherently incapable of simulating high speed highway-tire dynamics, but it is possible that the shearing stresses imparted by the tester can be adjusted to levels that may produce approximately similar effects. To test this idea, the wheel loading on the tester was reduced from 40 lbs. to 5 lbs. and several test discs were run. The premature crushing-smearing of the alkyd paint disappeared, and the test results shifted into greatly improved alignment with highway observations. A full set of correlation tests have now been scheduled for the 5 lb. wheel loading.

It is appropriate to observe here that the accelerated wear tester has exhibited almost from the beginning an ability to discriminate between good and poor traffic paints. The recent correlation difficulties are attributable in part to current efforts to measure smaller performance differences among a set of very good quality paints.

2. Highway Tests, Series III. Detailed observations were made on 1/14/65 (10 weeks). A snow and ice storm occurred the following week, so an additional observation was made on 1/21/65 to determine effects of tire chains on the paints. Damage from this cause was relatively minor. Performance differences among the paints of this study are not large. Bead-in technique does not greatly enhance paint durability. A two-coat application of the alkyd paint (beads-on both coats) has displayed outstanding performance to date.

3. Night Visibility. A proposal for some additional work in this area is in progress.

4. Other Activities. Consultation with the Highway Department Laboratory personnel on paint materials problems has continued. A design for a special type of testing facility is being developed.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Dr. F. Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

March 3, 1965

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 16
Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 February 1965 through 28 February 1965

Gentlemen:

Project activities for February are summarized as follows:

1. Accelerated Wear Testing. A complete set of tests is now nearing completion utilizing a 5 pound wheel loading in place of the previous 40 pound loading. This was undertaken in an effort to reduce a premature crushing-smearing of the alkyd control paint. It is now apparent that the exaggerated premature failure of the control has been corrected. Runs under Test Condition II (abrasive-erosive effects) at the 5 pound loading produce a consistent pattern of wear which orders the test paints from best to poorest as follows: Pliolite VT > Chl.Rubber-Alkyd > Epoxy Ester > Alkyd. Runs under Test Condition III (adhesion-chipping effects) at the 5 pound loading have not been found to produce any significant deteriorating effects for test periods up to 430 hours. Since the mode of test paint failures on the highway is almost entirely by chipping rather than abrasion, it is obvious that a means must be found to produce chipping effects on the wear machine if a positive correlation is to be achieved. Earlier work aimed at reducing paint adhesion by a light treatment of test panels with oil did not yield any significant performance differences. We are now preparing a panel with a much heavier treatment of a paraffin solution.

It is fully realized that the paraffin treatment represents a drastic expedient. However, if chipping paint failure can be produced by reduction of adhesion then a suitable standardized substrate for this purpose can be developed.

2. Highway Tests, Series III. This test series has matured rapidly, and detailed observations scheduled for 3/4/65 (16 weeks) may complete the significant data.

3. Night Visibility. Further searches of the patent literature have disclosed patents anticipating the basic conceptions developed in our work. U.S. No. 3,043,196 Palmquist - "Reflective Marking Aggregate" (1962) is most pertinent. In this connection, developmental work in this area is currently being concentrated on some test applications which conform to the program of Project No. A-802, "Hot Melt Traffic Marking Materials."

4. Other Activities. Work has been continued on special report drafts, and further plans for additional vehicle synthesis have been made.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

F. Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

May 6, 1965

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 17
Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 April 1965 through 30 April 1965

Gentlemen:

April project activities are summarized as follows:

1. Accelerated Wear Testing. Operation of the tester has continued on a full time basis to obtain adequate data on the chipping mode of failure. The findings indicate much more erratic film failures than those observed when abrasion resistance is being evaluated. The test is obviously very sensitive to the substrate texture and pretreatment. In a final effort to improve the reproducibility of this chipping resistance test, we have prepared discs of:

1) Plain glass
2) Plain glass, wax treated
3) Ground glass
4) Ground glass, wax treated
5) Transite
6) Transite, wax treated

The testing of these systems will be completed promptly and should clearly eliminate substrate variation as a source of erratic behavior.

Organization of data for a final report on the accelerated wear tester has been started.

2. Highway Tests. Experimental work has been completed on all test series. A report draft on the first series is complete, and drafting is in progress on series II and III.

3. Other Activities - Future Work. Immediate attention is being given to completion of accelerated wear testing and preparation of final reports.

The acquisition of a considerable volume of traffic paint performance data has not elucidated the relations which must exist between paint performance and basic physical properties of the films. In fact, basic physical properties have not been determined because of an emphasis on correlation of performance data. During the final period of the project, data will be accumulated on tensile stress-strain, adhesion, hardness, and any other pertinent film properties of the test paints so that subsequent interpretations of observed performance may become feasible.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

F. Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

June 8, 1965

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 18, Project No. HPS - 1(60) Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 May through 31 May 1965.

Gentlemen:

May project activities are summarized as follows:

1. Accelerated Wear Testing

A final series of accelerated wear tests to evaluate substrate effects on the chipping mode of failure was in progress during May. The results that have accumulated indicate large changes in wear rates with various substrates, but little or no change in the ordering of performance among the test paints.

2. Physical Tests

Panels of test paints have been subjected to conical mandrel flexibility, reverse impact, pencil hardness, and adherence tests both before and after an oven ageing period in a further effort to relate film properties to paint performance. The findings are to be included in the report on the accelerated wear tester.

3. Highway Tests

Report preparation work was continued.

4. Other Activities

The fundamental limitations of existing "simulation" testers including the accelerated wear tester have been recognized and reported previously. A conception of a testing facility capable of producing realistic tire-surface dynamics has been outlined for inclusion in the final report and as a basis for possible future developmental work.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

July 29, 1965

MAY 1969
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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 19, Project No. HPS - 1(60) Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 July through 31 July 1965.

Gentlemen:

Project work during the month of July has been directed exclusively to the preparation of final reports. A draft of Part I, Highway Cross-Stripe Tests of Traffic Paints, Series I has been completed and is now being processed for submission and approval. Data correlation and drafting of Parts II and III have been started.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

September 3, 1965

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 20, Project No. HPS - 1(60) Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 August through 31 August 1965

Gentlemen:

During August the drafting of Part II of the final report was the major project activity. This work should be complete early in September.

At the request of the Materials Laboratory, several samples of a black traffic paint were prepared and a formulation recommendation was submitted. Except for modification of pigmentation, this paint was very similar in composition to the present Georgia White specification.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

October 10, 1965

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. Emory C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Report No. 21 and Quarterly Progress Report No. 16, Project No. HPS - 1(60) Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints," Covering the period 1 September through 30 September, 1965

Gentlemen:

Project work during this period has been confined to the preparation of final reports.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
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November 3, 1965

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. Emory C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Report No. 22,
Project No. HPS - 1(60), Georgia Tech Project No. B-210,
"Use of Radioisotopes in Development of Test Methods and
Formulations for Traffic Paints," Covering the period
1 October through 31 October, 1965

Gentlemen:

Project work during this period has been confined to the preparation of final reports.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

December 7, 1965

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. Emory C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Report No. 23
Project No. HPS - 1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints," covering the period 1 November through 30 November 1965

Gentlemen:

Work on the Final Reports of this project is nearing completion. Section I, covering initial phases of the project and specifically Series I of the highway tests, has been printed in form for approval. Section II, describing Series II and III of the highway tests is complete and has been turned over to the Photo Lab for reproduction. Section III, summarizing the laboratory studies of this project, has been delayed in order to include certain material on the significance of physical studies. It is anticipated that this section will be completed during the current report period.

The complete three-section report should be ready to be submitted for approval sometime in January, 1966.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

January 10, 1966

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. Emory C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Report No. 24 and Quarterly Progress Report No. 17, Project No. HPS-1(60) Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints," Covering the Period 1 December through 31 December 1965

Gentlemen:

During the subject period Part III, the concluding section of the Final Technical Report of this project, has been completed and turned over to the Photo Lab for reproduction of the approval copies.

Approval copies of all three sections will be forwarded simultaneously when received.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

August 1, 1961

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State Highway Department of Georgia
2 Capitol Square S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineer

Subject: Quarterly Progress Report No. 1, Project No. B-210
"Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints"
Covering the Period May 1 to July 31, 1961.

Gentlemen:

The objectives of this research project are as follows:

1. Development of a device, utilizing radioisotopes, for the purpose of measuring the dry film thickness of highway paints, both in the laboratory and in the field.

2. Development of laboratory wear tests that can be correlated with the actual wear of traffic paints in highway use.

3. Development of special highway paint application equipment utilizing radioisotopes. This equipment will control the thickness of application and position the fresh stripe directly over the existing stripe.

4. Formulation of traffic paints, utilizing the devices and findings of the foregoing studies, to improve the performance of traffic paints.

The following report summarizes accomplishments in this field during the first quarter of this project.

I. Film Thickness Gauge

Inquires have been directed to the various instrument suppliers to determine the availability of suitable components for the beta back-scatter device. It now appears that the sensing head must be designed in detail; however, we are attempting to borrow the instrument developed and used by Dr. B. W. Pocock of the Research Laboratory, Michigan State Highway Department, to use as a starting point to become acquainted with the instrumental problems.

II. Wear Test Machine

Prior to initiation of this project, information had been accumulated on various types of laboratory abrasion machines for testing highway paints. The following design criteria were established for a test machine:

1. The machine must simulate as closely as possible the dynamics of vehicle tire wear on highway surfaces.

2. Means must be provided for adjusting the intensity of the wearing action.

3. Complete environmental control of the test surface must be possible to provide for hot, cold, wet, dry, freezing, and thawing conditions.

4. Consistent with the foregoing requirements, the machine should be as small and simple as possible and should be suitable for routine quality control testing as well as research purposes.

It was determined that the National Bureau of Standards machine described in Federal Specification TT-P-115A met most of the foregoing requirements; therefore, a similar machine was designed and built in the shop of the Engineering Experiment Station. A photograph of the completed machine is shown in Figure 1.

As shown in Figure 1, the wearing surface is in the form of a disc molded of concrete. Suitable forms and mixes were developed for this molding operation, and an advance inventory of discs was prepared and cured for the testing work.

III. Paint Formulations

Five types of paints have been selected for the testing program. These paints are identified as follows:

1. State of Georgia Specification 41A (varnish type)
2. Federal Specification TT-P-115A (alkyd type)
3. Parlon-alkyd type
4. Pliolite S-5 type
5. Lacquer type

The lacquer type paint is known to have inferior wearing qualities, and is included in the study to provide contrasting performance.

These paints are now being prepared for testing, and it is anticipated that abrasion testing will begin during the next month. In view of the practical importance of night visibility and of glass bead retention by paints, it was

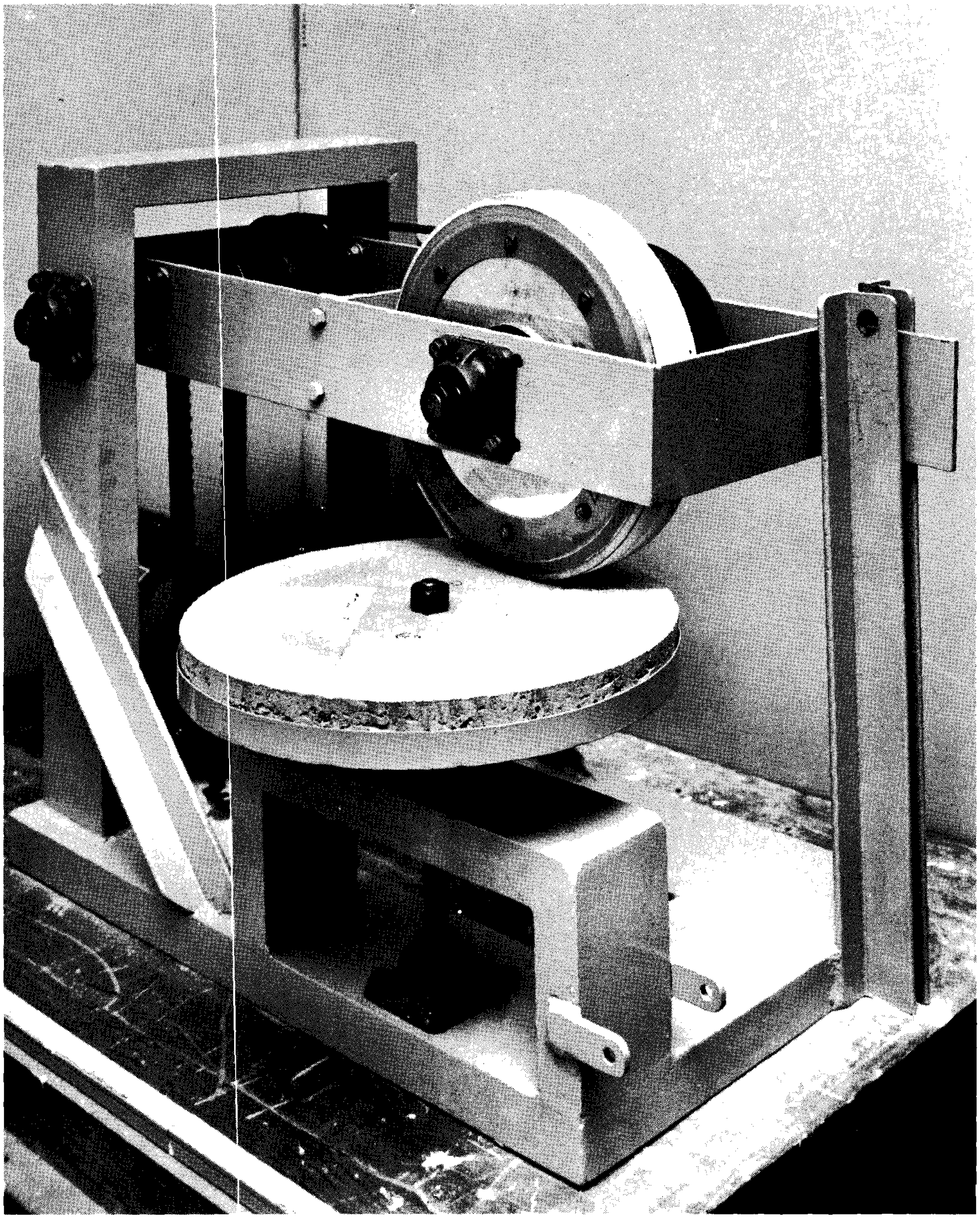

Figure 1. Wear Test Machine

decided that some studies of beaded paints would be run concurrently with unbeaded paint studies. For this purpose a night visibility meter was borrowed from the State Highway Department and is being reconditioned for use.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Wyatt C. Whitley, Chief
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

November 3, 1961

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineer

Subject: Quarterly Progress Report No. 2, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the Period August 1 through October 31, 1961

Gentlemen:

The following report summarizes accomplishments during the second quarter of this project.

I. Film Thickness Gauge

Attempts to borrow the device developed and used by Dr. B. W. Pocock of the Research Laboratory, Michigan State Highway Department, were unsuccessful, since that device is in intermittant use. However, Dr. Pocock very generously provided us with some drawings which were useful in the design and construction of a somewhat similar device. This device is now nearly complete, having been delayed through loss in transit of a part ordered from Tracerlab, Inc. This part has now arrived, and the thickness gauge is expected to be in operation this month.

II. Wear Test Machine

At our previous reporting, this machine had been constructed. A photograph attached to Progress Report No. 1 showed the machine together with a test disc of molded concrete.

Runs have been made using both molded concrete and transite as substrates for the paint stripes. The concrete surface is relatively irregular; consequently, there is considerable irregularity in the amount of wear from spot to spot over the surface. On the transite surface, wear is much more even; however, the paint dust abraded from the surface tends to accumulate as a ridge at about the center of the track of the abrading wheel. Means are now being provided for overcoming this latter difficulty by use of a vacuum attachment.

III. Paint Formulations

Progress Report No. 1 listed five types of paints which had been selected for the testing program. Paints representative of each of these types have now been formulated and prepared.

IV. Paint Stripe Applicator

An applicator has been designed for the purpose of depositing paint films of predetermined wet film thickness on the test panels. Construction of this applicator will be commenced within the next few days. It is anticipated that this applicator, or a modification of it, will also be used in depositing test stripes at highway sites when the program moves into a later phase.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Wyatt C. Whitley, ~~Chief~~
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

February 7, 1962

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineer

Subject: Quarterly Progress Report No. 3, Project No. HPS-1(60) Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period November 1, 1961 through January 31, 1962

Gentlemen:

Accomplishments of this project during its third quarter may be summarized as follows:

1. The film thickness gage employing a source of beta radiation and operating on the backscatter principle has been completed, and its capabilities have been evaluated.

2. The wear test machine has been modified to prevent "build-up" on the test panel.

3. Wear tests have been run on concrete and transite substrates, and comparative wear patterns have been measured.

4. A carriage for the paint stripe applicator has been constructed, and some components of the paint metering assembly have been completed.

5. Two additional paints have been added to the group of test formulations. Others, based upon epoxy and polyurethane bases, are contemplated.

Specific details are given in the following sections.

I. Film Thickness Gage

One of the objectives of this research project is the development of a device for the purpose of measuring the dry film thickness of highway paints, both in the laboratory and in the field. A laboratory model of such a device has now been completed and is shown in the attached figures as follows:

Figure 1. Diagram of Cross-Section, Showing Operation of Gage

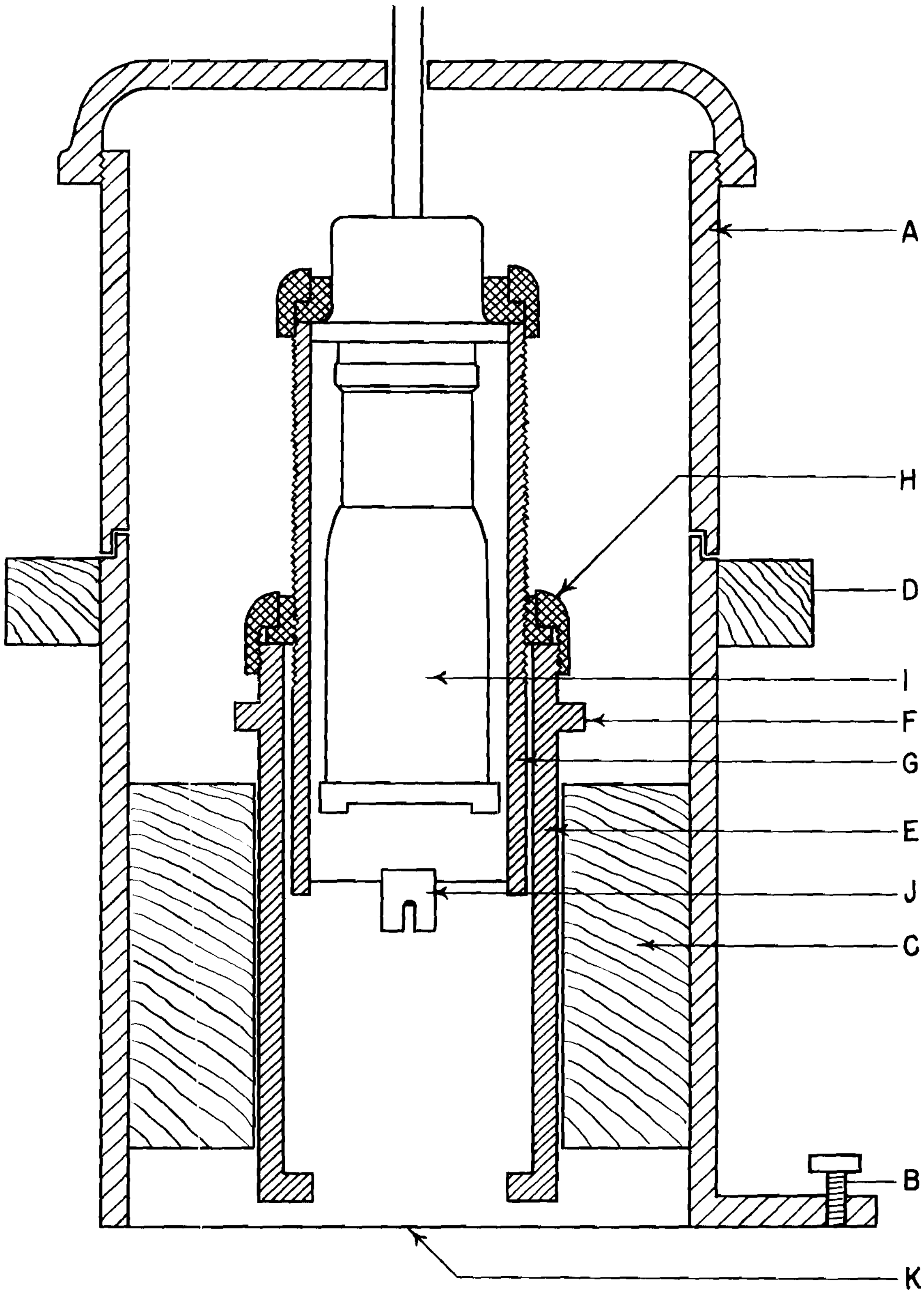


Figure 1. Cross Section of Beta Backscatter Thickness Gage.

Figure 2. Photograph of Film Thickness Gage Partially Disassembled.

Figure 3. Photograph of Film Thickness Gage in Operation and Attached to Decade Scaler.

Referring to Figure 1, it will be observed that the gage consists of the following parts:

1. An outer casing of steel (A) has three adjustable pedestal screws (B) for positioning the base of the case relative to the painted surface. A ring of hardwood (C) inside this casing serves to support the mounts of the Geiger tube when the gage is not resting on a surface. Hardwood handles (D) are provided on each side of the case.

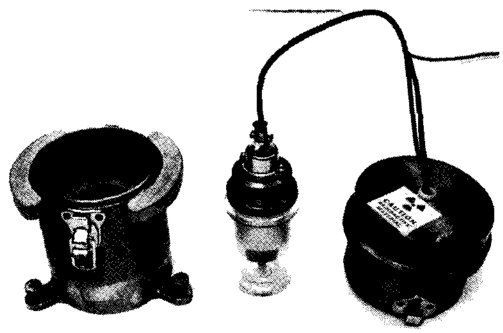
2. A plastic tube (E) fits loosely into the hole of the wooden ring, so that the bottom end of the plastic rests on the painted surface. When the gage is lifted, a shoulder (F) on this plastic member prevents its slipping on through the ring.

3. A second plastic tube (G) fits concentrically into the top of the first and is rigidly positioned by means of a lock ring (H). This tube supports the Geiger tube (I) and the beta radiation source (J). Positions of both may be adjusted vertically, so as to obtain the maximum sensitivity from the instrument.

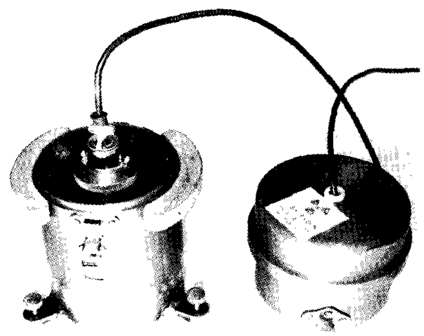
Radiation from the source (J) strikes and penetrates the painted surface (K). This radiation is scattered by the matter with which it comes into contact in the paint film, some of it finding its way back out of the paint film and up to the Geiger counter. Each ray that strikes the counter registers one count. As will be noted in Table I, counts from various materials range from 138 for air (i.e., no surface) to 17,346 for lead.

Operation of the device depends upon a difference in the backscattering characteristics of the paint film and the substrate. Obviously, if the paint film registers the same number of counts per minute as does the substrate, it will be impossible to tell anything about the film thickness from the count. The greater the difference in count from the paint and that from the substrate, the more accurate the measurement of film thickness will be. Table I shows the number of counts per minute obtained from various substrates, paint films, and wet paints. White paint shows a count of 3,930 per minute at infinite thickness (i.e., at such thickness that all of the backscatter is from the paint, none from the substrate), while yellow paint shows 8,717 and transite shows 4,415. The difference of 485 counts between white paint and transite is not as great as that between transite and yellow paint: 4,302; consequently, measurement of yellow paint film thickness is much more accurate by this method than is measurement of white paint film thickness.

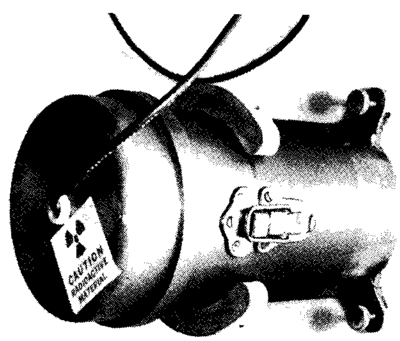
In practice, a curve is prepared for each type paint on each substrate, showing variation of counts per minute with paint film thickness. Readings from the scaler are then immediately translated into film thickness by reading



(A) Cover and Tube Assembly Removed



(B) Tube Assembly in Place



(C) Fully Assembled

Figure 2. Beta Ray Gage.

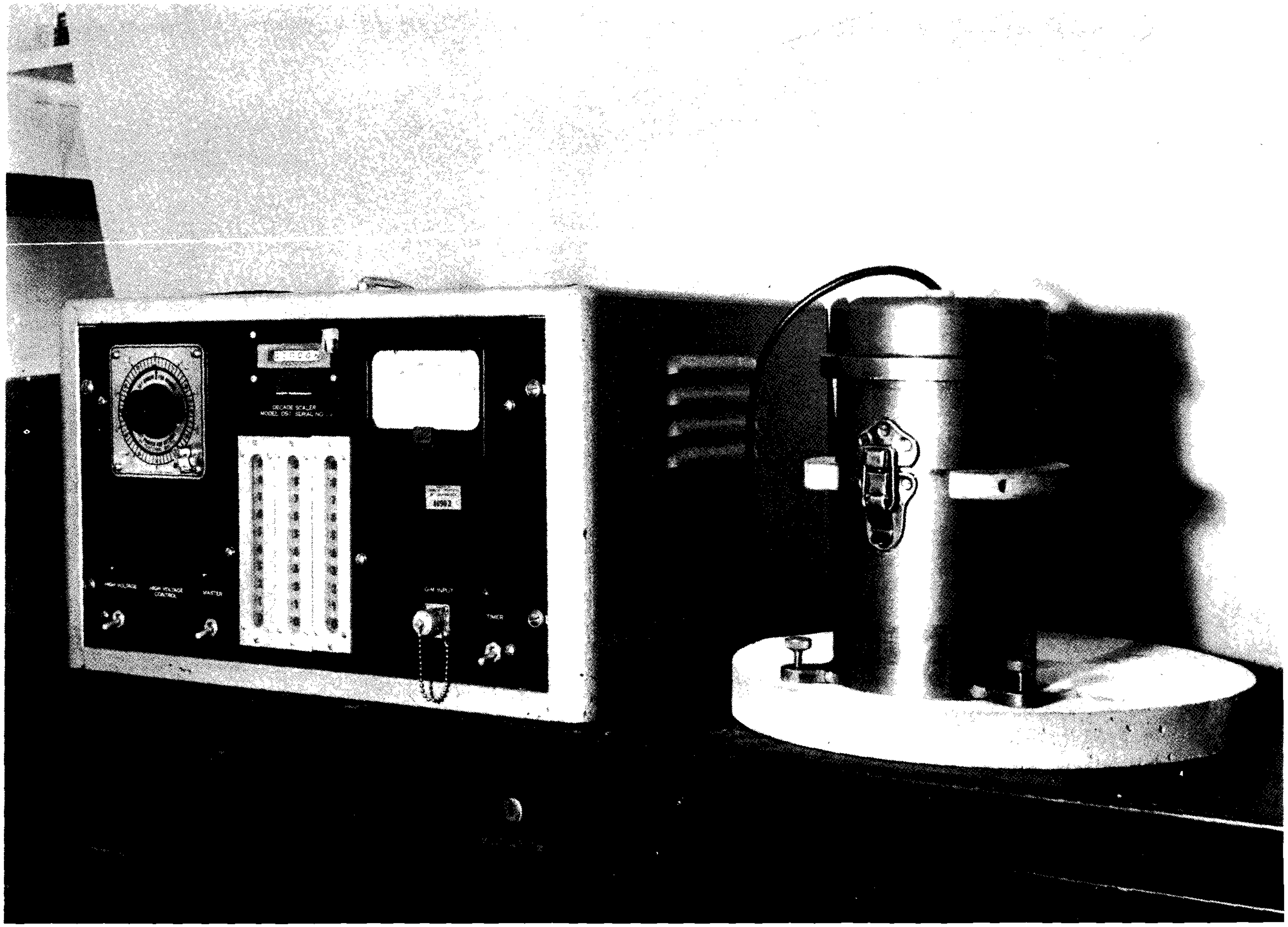


Figure 3. Complete Measuring Unit - Gage and Scaler.

TABLE I

BETA BACKSCATTER FROM VARIOUS SUBSTRATES

Substrate Material	Counts Per Minute
None (background)	138
Plywood	1,982
Plate Glass	4,210
Aluminum	4,970
Steel	8,730
Lead	17,346
Transite	4,415
Concrete	4,265
Liquid Paints:	
No. 1 Ga., yellow	6,840
No. 2 Alkyd, white	2,192
No. 5 Lacquer, white	2,018
Dry Paint Films on Transite:	
No. 1 Ga., yellow, 15 mils	8,717
No. 2 Alkyd, white, 15 mils	4,027

from the curve. Figure 4 shows a calibration curve plotted from measurements made on White Paint No. 3, while Figure 5 is the curve obtained with Georgia yellow traffic paint. In both instances, the curve starts at the value for the bare substrate and approaches asymptotically the value for infinite thickness of the paint film.

Initial studies with the thickness gage have included studies of various substrates (Table II), surface variations of concrete (Table III), surface variations of transite (Table IV), effects of position of sensing head on painted transite (Table V), effects of film thickness of Paint No. 2 on transite (Table VI), effects of film thickness of Paint No. 3 on transite (Table VII), and effects of wear on Paint No. 1 (Georgia yellow) (Table VIII).

II. Wear Test Machine

Early test runs with the wear test machine presented a problem which had not previously been reported in the literature with reference to machines

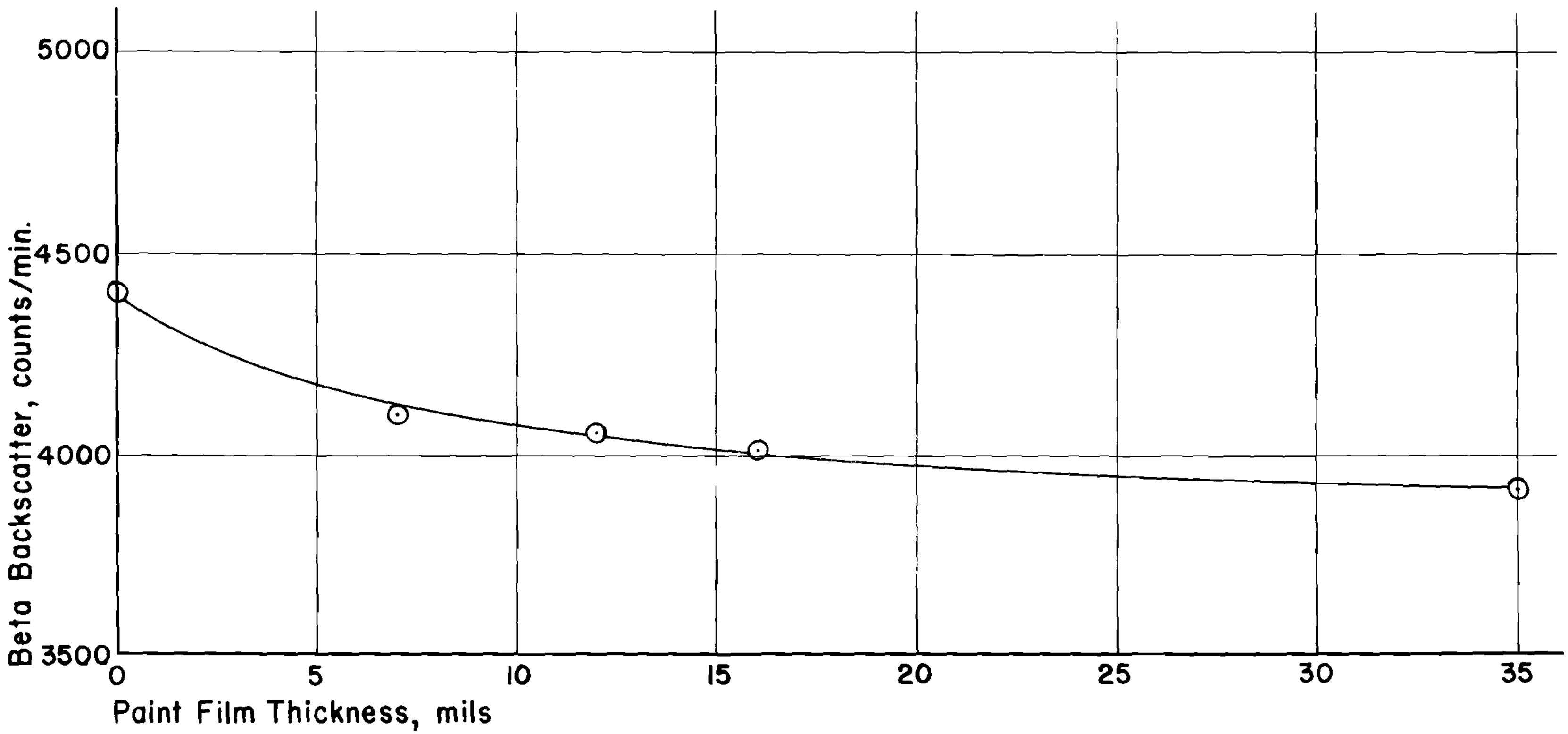


Figure 4. Counting Rate *vs*. Thickness for No. 2 White Traffic Paint on Transite.

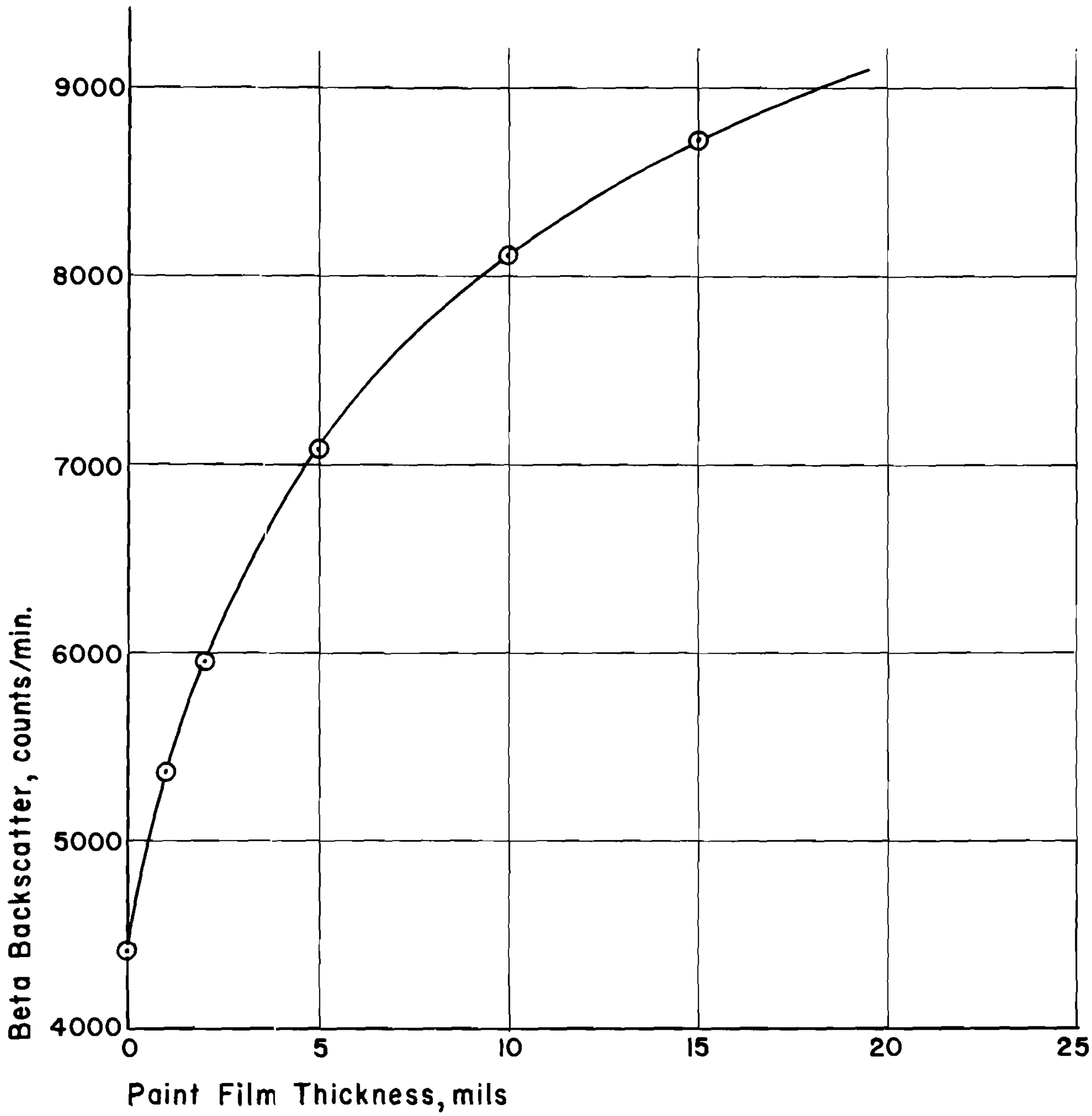


Figure 5. Counting Rate vs. Thickness for Georgia Yellow Traffic Paint on Transite.

TABLE II

BETA BACKSCATTER FROM VARIOUS SUBSTRATES, MIN^{-1}

Material	Replicate Counts				Average	Range
None (background)	149	144	120	138	138	29
Plate Glass, 1/4"	4,246	4,161	4,254	4,177	4,210	93
Aluminum Plate, 1/4"	4,887	4,992	4,976	5,021	4,970	134
C.R.Steel Sheet, 1/4"	8,693	8,713	8,799	8,723	8,730	106
Plywood, 1/2"	1,971	1,988	1,925	2,054	1,982	129
Lead Sheet, 1/8'	17,086	17,496	17,421	17,379	17,346	410

TABLE III

EFFECT OF SURFACE VARIATIONS ON BETA BACKSCATTER OF CONCRETE SLABS, COUNTS PER MINUTE

Material	Replicate Counts				Average	Range
Smooth (Top) Side Position 1	4,189	4,264	4,154	4,194	4,200	110
Smooth (Top) Side Position 2	4,075	4,329	4,194	4,269	4,217	254
Rough (Bottom) Side Position 1	4,191	4,050	4,325	4,180	4,187	275
Rough (Bottom) Side Position 2	4,179	4,155	4,109	4,100	4,136	79

TABLE IV

EFFECT OF SURFACE VARIATIONS ON BETA
BACKSCATTER OF TRANSITE SLABS, COUNTS PER MINUTE

Material	Replicate Counts				Average	Range	Standard Deviation
Position 1	4,456	4,461	4,491	4,459	4,467	35	24
Position 2	4,426	4,372	4,368	4,344	4,377	82	39
Position 3	4,344	4,496	4,413	4,329	4,395	167	68
Position 4	4,454	4,424	4,401	4,400	4,420	64	24

TABLE V

EFFECTS OF ANGULAR AND ELEVATIONAL POSITIONING
OF SENSING LEAD ON BETA BACKSCATTER OF
PAINTED TRANSITE (7 MILS PAINT NO. 2), COUNTS PER MINUTE

Material	Replicate Counts				Average	Range
Normal Position	4,336	4,224	4,171	4,184	4,229	165
Case Elevated 9/32" Sensor makes surface contact	4,296	4,182	4,211	4,298	4,247	116
Sensor Elevated 5/16"	3,327	3,328	3,279	3,356	3,322	77
Sensor Angled 5°	4,069	4,103	4,139	4,103	4,103	70

TABLE VI

EFFECTS OF FILM THICKNESS OF PAINT NO. 2
ON BETA BACKSCATTER OF TRANSITE, COUNTS PER MINUTE

Material	Replicate Counts				Average	Range	Standard Deviation
7 Mil Film, Position 1	4,161	4,107	4,196	4,089	4,117	107	87
7 Mil Film, Position 2	4,105	4,024	4,046	4,119	4,072	95	40
7 Mil Film, Position 3	4,046	4,141	4,055	4,078	4,082	95	53
7 Mil Film, Position 4	4,125	4,169	4,136	4,079	4,127	90	35
12 Mil Film	4,119	4,017	4,054	4,071	4,065	102	17
16 Mil Film	4,061	3,998	4,049	4,005	4,027	63	28
35 Mil Film	3,952	3,930	3,936	3,878	3,922	74	40

TABLE VII

EFFECTS OF FILM THICKNESS OF PAINT NO. 3
ON BETA BACKSCATTER OF TRANSITE, COUNTS PER MINUTE

Material	Replicate Counts				Average	Range
Unpainted	4,594	4,495	4,553	4,511	4,538	99
10 Mils Paint	4,141	4,234	4,186	4,216	4,194	93
20 Mils Paint	4,026	4,039	4,146	3,926	4,034	220
30 Mils Paint	3,900	4,016	4,109	4,179	4,051	279

TABLE VIII

EFFECTS OF WEAR ON BETA BACKSCATTER OF
PAINT NO. 1 (GA. YELLOW), COUNTS PER MINUTE

Material	Replicate Counts				Average	Range
15 Mils, Unworn	8,746	8,684	8,744	8,694	8,717	62
Worn 45, 000 Cycles	7,985	7,879	7,854	8,024	7,935	170

of this kind. Quarterly Progress Report No. 1 (August 1, 1961) includes a photograph of this machine with a painted concrete test panel in position under the abrading wheel. As tests were transferred to transite panels, it was soon observed that a ridge was building up in the middle of the path of the abrading wheel on the test panel. This appeared to be due to fine particles of dust abraded from the paint surfaces, clinging to the abrading wheel, and being redeposited on the test panel. Passing through a number of such cycles, the particles would be gradually moved from the outer portions of the track to the middle through action of the torque of the abrading wheel against the test panel surface.

A vacuum attachment has now been obtained and attached to the machine. Initial experiments included various positions of the brush and vacuum head on the test panel. However, the most effective location for both is a position on the abrading wheel approximately 135 degrees past its point of contact with the test panel. This installation has eliminated the ridge effect entirely. Several of the test paints at various film thicknesses have now been run on both concrete and transite surfaces. A photograph of some of the test panels is shown in Figure 6. Findings of these tests may be summarized as follows:

1. The abrading wheel does not wear the paint film uniformly. Maximum wear occurs at the outer edges of the wheel; minimum wear at a point slightly off the midline of the wheel, away from the center of the test disk.

This effect is contrary to what might be expected. Because of the turning of the test disk, there is some pushing of the wheel against the disk at the inner diameter of the wear track and some drag at the outer diameter. One would expect these forces at the edges to produce greater wear than at the midline of the wheel, where these forces are negligible. These effects are being given further study.

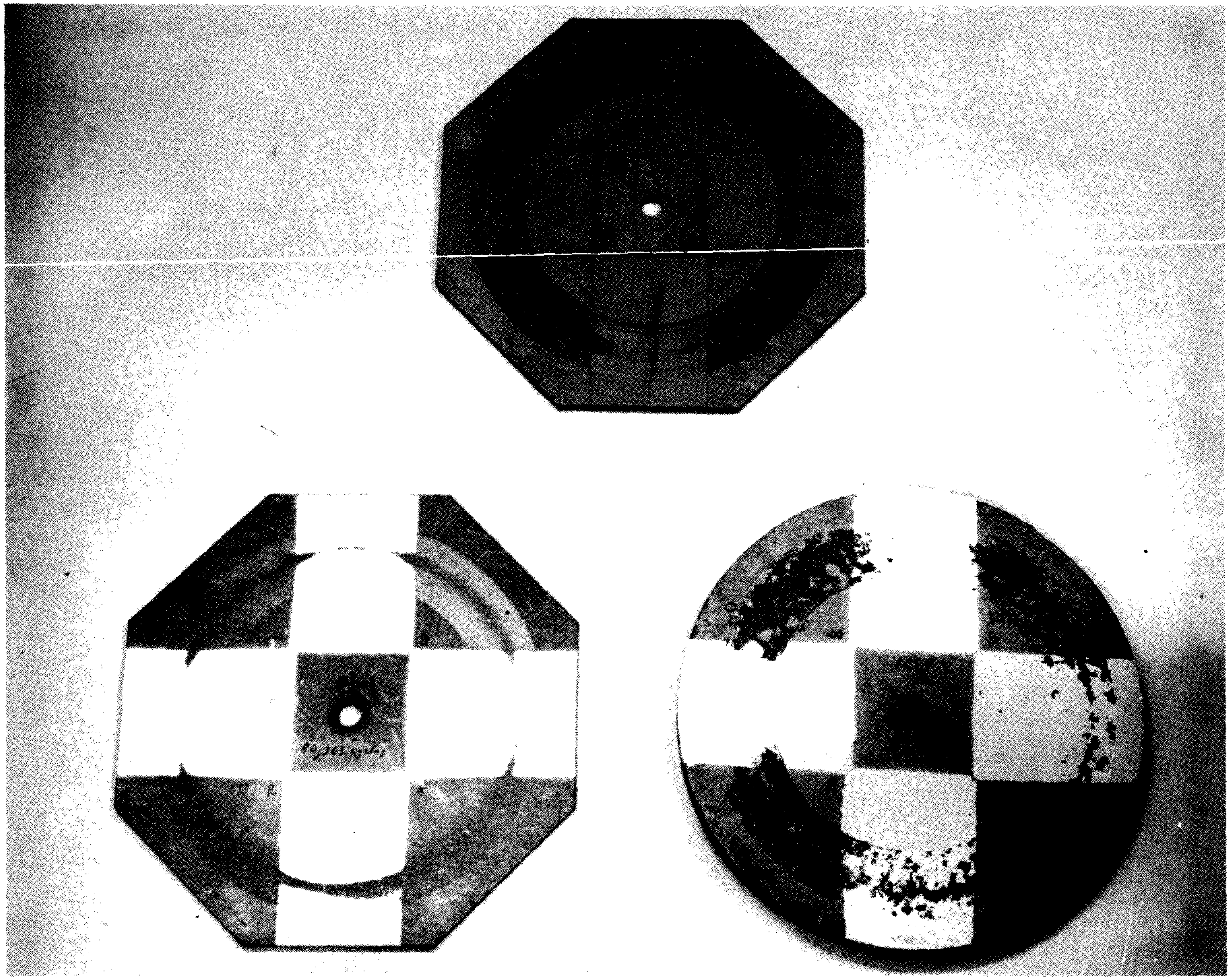


Figure 6. Wear Test Panels.

2. The wear pattern on concrete is more random than on transite. This is primarily a result of the naturally rougher surface of concrete, where bumps wear through rapidly and pits retain paint without wearing. For this reason, the extent of wear is more difficult to assess on the concrete substrate. In this regard, the beta backscatter gage has an advantage over optical gages in that it integrates measurements over an area of approximately 2.4 square inches of surface at each reading.

3. The order of performance of the various paints appears to be similar on both concrete and transite.

4. The importance of paint film thickness as a major factor in wear assessment is confirmed by these tests.

III. Paint Formulations

Two additional paints have been added to the group of test formulations. Compositions of these paints are as follows:

Paint No. 6, White Vinyl Toluene/Butadiene Traffic Paint, BX 85-J-98

Pigment	Pounds/100 Gal. Batch
Titanox RCHT	296
Titanox RANC	59
Fibrene C-400	53
Celite 261	83
Mineralite 3X	59
Bentone 38	5
Vehicle	
Pliolite VT-L	107
Velsicol X-37	35
Chlorinated Paraffin, 40%	35
Soya Lecithin	8
Tolusol	357
Total Pounds per 100 gallons	1,097
Weight per gallon	11.0 lb.
P. V. C.	51.5%

Paint No. 7, White Chlorinated Rubber-Alkyd Traffic Paint

Pigment	Pounds/100 Gal. Batch
Titanox RCHT	590
Asbestine 3X	73
Keystone Whiting	73

Paint No. 7 (Continued)

Vehicle	Pounds/100 Gal. Batch
Parlon S-10	45
65% Soya-PE Alkyd	176
Soya Lecithin	9.1
Epichlorohydrin	1.3
6% Cobalt Naphthenate	1.3
Antiskinning Agent	1.3
Toluene	304
Mineral Spirits	31
Total Pounds per 100 gallons	1,305
Weight per gallon	13.05 lb.
P. V. C.	55%

These two formulations are of current interest as candidates for inclusion in a revised Federal Specification for traffic paints.† Samples of paints prepared according to the above formulations are currently on hand for inclusion in the test program.

IV. Paint Stripe Applicator

A wheeled carriage for the applicator has been constructed, including cone-pulley and belt transmission from the wheels to the pumping assembly. Portions of the pumping assembly have been attached. Some design modifications in the paint feed mechanism were required, and this work is currently in progress.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Wyatt C. Whitley, Chief
Chemical Sciences Division

†Formulations were supplied on the suggestion of Mr. Harold Allen, Chief, Bureau of Public Roads.

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

July 23, 1962

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineer

Subject: Quarterly Progress Report No. 4, Project No. HPS-1(60) Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 April 1962 through 30 June 1962.

Gentlemen:

Project activities during this report period have included:

1. Minor modifications, calibration, and working tests of the volumetric paint stripe applicator.
2. Reformulation of some of the selected paints to correct certain observed defects such as poor shelf stability, and to obtain quantities adequate for the field test program.
3. Site selection and detailed plans for the field tests.
4. Continued testing on the abrasion tester under both wet and dry conditions.
5. Design of a simple reflective bead applicator.

Details of the work are given below:

I. Paint Stripe Applicator

An air separator and pressure regulator were mounted on the carriage of the volumetric paint stripe applicator previously described (1). A high pressure air source was connected to the applicator by a 50 ft. trailing hose. This was found to supply very satisfactory pressure and volume of air to the spray gun and delivery of paint to the gun by the drive mechanism and cylinder is very positive and accurate.

Operation of the applicator disclosed that the inclined plane assembly was not sufficiently rigid, so a heavier and stronger member was substituted.

It was noted that after about 20 feet of line had been sprayed, accumulated overspray on the mask began to drip over the edges, producing snaking thin lines of paint on the concrete on both sides of the stripe. To correct this condition,

(1) Annual Report No. 1, p. 9

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a duplicate mask was made which permits one mask to be in use while the other is being cleaned.

The applicator has been calibrated so that predetermined paint film thicknesses may be obtained by appropriate settings on the inclined plane scale.

II. Reformulation

Of the highway paints previously prepared and described in Annual Report No. 1, shelf stability was found to be inadequate in several cases. These paints were originally prepared in quantities of approximately 3/4 gallons, and since nearly a quart had been consumed in laboratory testing, in some cases only about 1/2 gallon remained for field tests. Accordingly, most of the test paints were reformulated, and a full one-gallon batch was prepared. Formulation data on all items not previously given are attached to this report.

III. Field Tests

The desired location for field tests was one carrying heavy traffic and providing both concrete and asphalt surfaces. Such a site was found on Atlanta's northeast expressway at the bridge over Lenox Road. South of this bridge the surface is concrete; north of the bridge the surface is asphalt. The paint tests at this location will include nine different paints applied to concrete and asphalt at 10, 15, and 20 mils wet film thickness, with and without reflective beads. This will require 12 stripes of each paint for a total of 108 stripes.

Application and evaluation of the paints will be in accordance with A.S.T.M. testing procedures and standards.

In addition to visual evaluations, the beta ray film thickness gage will be employed to measure initial film thicknesses and to assess wear effects. A low angle reflectometer or night visibility meter will be used to observe changes in this important performance quality of the paints.

IV. Laboratory Abrasion Tests

Abrasion tests have been run on all of the originally prepared group of paints, on both wet and dry painted transite panels. A summary of some of the results of these tests is given in Table I. This work has demonstrated that a control paint must be used on every panel for testing, since the number of cycles to failure varies rather widely upon replication. Accordingly, Table I should be viewed only in terms of the indicated broad trends, rather than attempting to make fine discriminations.

It will be noted that:

1. Wet abrasion is far more severe than dry abrasion.
2. The Georgia Specification paints compare favorably with other conventional types.
3. Epoxy and polyurethane based paints exhibit a potential for greatly enhancing the durability of traffic paints.

TABLE I

ABRASION TESTS OF VARIOUS PAINTS ON TRANSITE SUBSTRATE

Doctor Blade Clearance: 20 mils

Wet Film Thickness: appr. 15 mils

Paint No.	Description	Cycles to Failure* Dry	Wet
1	Ga. Yellow	+31,200	+32,300
2	TT-P-115	67,900	11,600
3	Pliolite	+70,000	15,200
4	Chlor. Rubber	+70,000	27,000
5	Lacquer	52,800	+17,000
6	Goodyear (Pliolite)	37,900	12,500
7	Hercules (Chlor. Rubber)	47,500	+23,400
8	Epoxy-Amine	+428,000	+27,000
9	Epoxy-Polyamide	+428,000	+27,000
10	Polyurethane	+104,000	+23,000
11	Ga. White	33,000	17,600

*Where a plus sign (+) preceeds the value, the test was terminated prior to failure. Generally, this was done in order to preserve other stripes on the same panel as a record of comparative wear. Future tests will be made on panels containing a control stripe, thus permitting more accurate comparison among all of the test paints.

V. Bead Applicator

Laboratory work has thus far been confined to unbeaded paints; however, for the field tests it was decided that both beaded and unbeaded lines would be tested. The requirements for bead application are not judged to be as critical as for the paint itself; therefore, a relatively simple bead distributor has been designed. This device consists of a small two-wheeled carriage supporting a slender plywood box in vertical position. The beads will flow from a container near the top of the box, through a metering orifice, and bounce against three distributing baffles before striking the wet stripe beneath the carriage. The carriage will be rolled by the operator at a proper rate to attain the desired beading density.

Future Work

The field test application will be followed up with periodic inspections and beta-ray gaging. In parallel with this work, further more comprehensive laboratory abrasion testing will be conducted utilizing transite, concrete, and asphalt surfaces. The application performance as observed in the field will provide guidance for further formulation work aimed at developing field-practical paints with the more durable types of vehicles.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Project No. B-210

Date

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 10

Polyurethane Traffic, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	36.5	14.9				
Rutile 510 - TiO_2	47.5	35.1	228	35.0	6.5	776
Calwhite	31.3	35.7	150	22.6	6.6	511
Celite 281	20.0	27.0	96	19.2	5.0	327
Bentone 27	1.3	2.2	6	14.2	0.4	20
			480		18.5	1634
	100.1	100.0				
VEHICLE	63.5	85.1				
Tolylene Diisocyanate	1.7	1.5	14	8.5	1.6	47.7
Toluene	48.0	52.3	400	7.25	55.2	1362
* Spenkel M86 - 50CX	50.4	46.2	420	8.6	48.8	1430
			834		105.6	2839.7
	100.1	100.0	1314		124.1	4473.7

*Pigments are slurry-ground with T.D.I. prior to incorporation of Spenkel

WEIGHT PER GALLON 10.6 LBS.

P.V.C. 45.8 %

TOTAL SOLIDS:

WEIGHT 52.5 %

VOLUME 32.6 %

Project No. B-210

Date

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 11

Ga. specification 41A, White

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT	55.0						
ZnO	5						
Asbestine	25						
Lithopone	55						
TiO_2	15						
	100						
VEHICLE	45.0						
Synthetic resin	20.2						
Tung oil	22.5						
Conc. (cobalt) Naphtha	2.3						
Petroleum Naphtha	41.3						
Benzol	13.8						
	100.1						

WEIGHT PER GALLON ______ LBS.

P.V.C. ______ %

TOTAL SOLIDS:

WEIGHT ______ %

VOLUME ______ %

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 13

Lacquer type traffic paint, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams	
PIGMENT	25.7	10.4					
Rutile 610 - TiO_2	24.7	17.1	63.0	35.0	1.8	299	
Gamaco	54.1	58.1	137.9	22.6	6.1	655	
Celite 281	9.8	12.4	25.0	19.2	1.3	120	
Nytal 300	10.3	10.5	26.2	23.8	1.1	123	
Bentone 27	1.1	1.9	2.8	14.2	0.2	13	
	100.0	100.0	254.9		10.5	1210	
VEHICLE	74.3	89.6					
1/2 sec N/C - 25%	50.5	47.3	373.2	8.7	42.9	1777	
Amberol 800 - 50%	9.3	9.2	69.0	8.3	8.3	328	
Flexol 8HP	10.6	10.1	78.2	8.5	9.2	372	
Lacquer Thinner*	29.5	33.3	217.9	7.2	30.2	1035	
Ethanol 10 Butanol 5 Ethyl Acetate 20 Butyl Acetate 15 Toluene 50			738.3		90.7	3512	
	99.9	99.9	993.1		101.2	4722	

300 g thinner used for grinding.

WEIGHT PER GALLON 9.8 LBS.

P.V.C. 47.5 %

TOTAL SOLIDS:

WEIGHT 38.5 %

VOLUME 21.8 %

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 14

Epoxy Amine, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams	
PIGMENT	47.6	22.7					
Rutile 610 - TiO_2	21.6	16.1	150	35.0	4.65	680	
Gamaco	32.1	34.1	223	22.6	9.87	1030	
Celite 281	10.5	13.2	73.2	19.2	3.81	332	
Nytal 300	34.9	35.2	242.5	23.8	10.19	1100	
Bentone 27	0.9	1.5	6.0	14.2	.42	27	
	100.0	100.1	694.7		28.94	3168	
VEHICLE	52.4	77.3					
Araldite 571 - T - 75	42.6	35.5	325	9.3	35.0	1475	
Methyl Ethyl Ketone	26.3	30.9	201	6.6	30.5	910	
Toluene	25.7	28.0	196	7.25	27.6	890	
U F Beetle 216 - 8	1.6	1.4	12	8.6	1.4	54	
Butanol	1.9	2.3	14.7	6.5	2.25	67	
Diethylene Triamine	1.9	1.8	14.7	8.2	1.80	67	
			763.4		98.55	3463	
	100.0	99.9	1458.1		127.49	6631	

1500g MEK, toluene used for grinding,
Beetle added after grinding,
2.1g catalyst for 100g batch.

WEIGHT PER GALLON 11.4 LBS.

P.V.C. 53.1 %

TOTAL SOLIDS:

WEIGHT 64.8 %

VOLUME 42.6 %

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 15

TT - P - 115, White

	% WEIGHT	% VOLUME	100 GALLON BATCH			
			Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	48.0	21.2				
Rutile 610 - TiO_2	29.8	20.8	150	35.0	4.3	680
Gamaco	29.8	32.4	150	22.6	6.7	680
Celite 281	19.8	25.1	100	19.2	5.2	454
Nytal 300	19.8	20.3	100	23.8	4.2	454
Bentone 38	0.8	1.4	4	15.0	0.3	18
	100.0	100.0	504		20.7	2286
VEHICLE	52.0	78.8				
Alkyd P 670-55	69.1	65.8	377	7.5	50.3	1710
VM & P Naphtha	28.2	32.0	154	6.3	24.5	700
Cobalt Naphth. - 6%	0.5	0.5	3.0	8.0	0.4	13.6
Lead Naphth. - 24%	1.4	1.0	7.5	9.6	0.8	34
Mn Naphth. - 6%	0.2	0.3	1.0	8.1	0.2	4.5
Adv. Anti-skin agent	0.6	0.5	3.5	7.8	0.4	15.9
			546.0		76.6	2478.0
	100.0	100.1	1050		97.3	4764.0

200g VM & P used for grinding

WEIGHT PER GALLON 10.8 LBS.

P.V.C. 48.0 %

TOTAL SOLIDS:

WEIGHT 68.1 %

VOLUME 44.3 %

Project No. B-210

Date 6/22/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 16

Parlon Alkyd Traffic Paint, White

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	grams
PIGMENT	60.2	32.6				
Rutile - 610 TiO_2	24.8	17.2	208	35.0	5.9	786
Gamaco	54.8	59.3	460	22.6	20.4	1739
Nital 300	10.0	10.2	83.5	23.6	3.5	316
Celite 281	10.0	12.5	83.5	19.2	4.3	316
Bentone 38	0.5	0.9	4.0	15.0	0.3	15
	100.1	100.1	839.0		34.4	3172
VEHICLE	39.8	67.4				
Parlon S-10 30% in toluene						
Toluene	19.5	21.0	108	7.25	14.9	408
Parlon S-10	8.4	4.8	46.4	13.6	3.4	175
Alkyd P - 296 - 70	51.6	52.3	286	7.7	37.1	1081
Toluene	19.1	20.6	106	7.25	14.6	400
Propylene Oxide	0.5	0.6	3	7.5	0.4	11
Co Naphth. - 6%	0.3	0.3	1.5	8.0	0.2	6
Adv. Anti-skin agent	0.5	0.6	3	7.8	0.4	11
			553.9		71.0	2092
	99.9	100.2	1392.9		105.4	5264

300g toluene for grinding

WEIGHT PER GALLON 13.2 LBS.

P.V.C. 56.7 %

TOTAL SOLIDS:

WEIGHT 77.9 %

VOLUME 57.3 %

Project No. B-210

Date 6/29/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 17

Polyurethane traffic, white

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams	
PIGMENT	44.3	20.1					
R - 610 TiO_2	47.4	35.1	207	35.0	5.92	940	
Gamaco	31.4	35.8	137	22.6	6.04	622	
Celite 281	19.9	26.9	87	19.2	4.55	395	
Bentone 27	1.2	2.2	5.4	14.2	.38	25	
			436.4		16.89	1982	
	99.9	100.0					
VEHICLE	55.7	79.9					
Tolylene Diisocyanate	2.4	2.2	13	8.5	1.5	59	
Toluene	28.1	31.6	154	7.25	21.2	700	
*Spenkel M86 - 50CX	69.7	66.2	382	8.6	44.40	1734	
			549		67.1	2493	
	100.2	100.0	985.4		84.0	4475	

700g Toluene used for grinding

*Pigments are slurry-ground with T.D.I. prior to incorporation of Spenkel.

WEIGHT PER GALLON 11.7 LBS.

P.V.C. 45.9 %

TOTAL SOLIDS:

WEIGHT 63.7 %

VOLUME 43.8 %

Project No. B-210

Date 6/29/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 18

Epoxy Polyamide, White

	% WEIGHT	% VOLUME	100 GALLON BATCH			
PIGMENT	53.5	28.6	Pounds	Lbs. Per Solid Gal.	Gallons	lab batch
Rutile - 610 - TiO_2	29.4	20.5	145	35.0	4.15	659
Gamaco	29.4	31.7	145	22.6	6.42	659
Celite 281	20.1	25.5	99	19.2	5.17	450
Nytal 300	20.1	20.6	99	23.6	4.17	450
Bentone 27	1.1	1.8	5.3	14.2	.37	24
	100.1	100.1	493.3		20.28	2242
VEHICLE	46.5	71.4				
Polyamide 815	24.5	25.5	105	8.1	12.9	477
Toluene	15.4	18.0	66	7.25	9.1	300
Cellosolve Solu.	15.4	17.0	66	7.7	8.6	300
U. F. Beetle 216 - 8	1.6	1.5	6.7	8.6	.78	30
Araldite 502	43.2	38.1	185	9.56	19.3	840
			428.7		50.68	1947
	100.1	100.1	922.0		70.96	4189g.

600g thinner used for grinding,
Beetle added after grinding.
30.5g catalyst for 100g of batch.

WEIGHT PER GALLON 13.0 LBS.

P.V.C. 39.0 %

TOTAL SOLIDS:

WEIGHT 85.4 %

VOLUME 74.7 %

Project No. B-210

Date 7/2/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 19

EPON resin formulation XYA-200
white traffic paint
(Supplied by Shell Chemical Co.)

	% WEIGHT	% VOLUME	100 GALLON BATCH			
			Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	52.5	25.0				
RCHTX - TiO_2	60.9	57.7	386	26.9	14.3	1752
Asbestine 3X	38.8	41.5	246	23.9	10.3	1117
Al. Stearate #909	0.3	0.8	2	10.0	0.2	9
			634		24.8	2878
	100.0	100.0				
VEHICLE	47.5	75.0				
EPON 1001-A-80	20.8	17.4	119	9.3	12.93	540
EPON 1001*CT*55	30.2	27.7	173	8.4	20.57	785
Acetone	33.2	38.9	190	6.6	28.9	863
Toluene	12.2	13.0	70	7.25	9.6	318
Beetle 216-8	1.7	1.5	10	8.5	1.1	45.4
Curing Agent U	1.9	1.8	11	8.5	1.3	50
			573		74.4	2601.4
	100.0	100.3	1207		99.2	5479.4

WEIGHT PER GALLON 12.2 LBS.

P.V.C. ______ %

TOTAL SOLIDS:

WEIGHT 68.8 %

VOLUME ______ %

October 22, 1962

GEORGIA TECH RECEIVED MAY 8 1969 LIBRARY

State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineer

Subject: Quarterly Progress Report No. 5, Project No. HPS-1(60) Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 July 1962 through 30 September 1962

Gentlemen:

Project activities during the period covered by this report are summarized as follows:

1. Continued testing of paints on the abrasion testing machine.
2. Application of test paints at the selected highway site.
3. Test observations and analysis of data from laboratory and highway tests.

This work is described in more detail below.

I. Laboratory Abrasion Testing

Initially it was planned to test each of the nine selected paints on both wet and dry surfaces of transite, concrete, and asphaltic concrete. The transite tests have been completed and the concrete tests are approximately one-half completed. The asphalt tests were deferred because of difficulties in producing satisfactory panels. In view of the findings to date, it would not be of any value at present to extend the testing technique to the asphaltic surface.

One fact in the laboratory abrasion testing work stands out in sharp relief. The indicated abrasion resistance, wet and dry, on both transite and concrete, of catalyzed epoxy paints is at least <u>several</u> <u>times</u> that of "conventional" paints. For example, a conventional paint may wear through at 25,000 cycles dry and 10,000 cycles wet, while the poorest catalyzed epoxy tested ran in excess of 75,000 cycles dry and 50,000 cycles wet. In most cases the durability of the epoxy was so great as to render testing to failure impractical. Thus the laboratory abrasion tester provides a consistently large spread in performance between the epoxies and conventional paints.

Comparisons among the various conventional paints are not so well-defined. As stated in the previous report, it was found necessary to include a control paint (Paint No. 15, Federal Specification TT-P-115) on every test panel and to report individual paint performance as a percentage of the control. Reversals in indicated performance among replicate panels are not uncommon. Despite this difficulty, it would be premature at this time to assume that the laboratory abrasion tester does not adequately discriminate among these paints. It would not be surprising to discover that several of these paints are substantially equivalent in service performance.

However, certain control and measurement difficulties with the laboratory abrasion tester should be recognized. It has been found that application of uniform wet paint films is best accomplished with a doctor blade. Even so, thickness variations of 10 per cent can easily occur on a transite surface and this could produce a corresponding variation in indicated abrasion resistance. On concrete the errors may be expected to be much greater, and when differences in paints are not large the indicated abrasion resistance may be more nearly a function of the concrete surface profile than of the characteristics of the paint.

Observations of abrasion tend to be only semiquantitative in nature. On transite panels, the painted sections show wear at the leading and trailing edges near the center of the wheel track. These worn areas grow inward from the edges and eventually join near the center. This joining has been defined as the end point of the test. On concrete panels, the wear is so erratic that the end point has merely been defined by the exposure of an estimated 50 per cent of the concrete beneath the paint film.

Test results for the completed series of abrasion tests on transite are assembled in the attached table in comparison with the highway tests at 4 weeks' exposure.

II. Highway Test Applications

On August 1, 1962, test paints No. 6, 11, 13, 14, 15, 16, 17, 18 and 19 were applied to a test site on the Northeast Expressway at the Lenox Road Bridge. The paints were applied transversely to the outer lane of the northbound section on concrete south of the bridge and on asphalt north of the bridge. Each paint was applied with the Paint Stripe Applicator at wet film thicknesses of 10, 15 and 20 mils, unbeaded and beaded, on concrete and on asphalt. Beading was applied at a rate of approximately 6 pounds per gallon of paint using a simple applicator constructed for this purpose. Of the various paints applied, only Paint No. 14 caused equipment difficulties. This amine-catalyzed epoxy paint has previously been observed to exhibit excessive "puffiness" or thixotropy. It caused repeated clogging of the spray gun, and after several lines were applied on the asphalt surface further attempts to apply this material were abandoned. During the application work, primary attention of the operators was directed toward obtaining the specified coating thickness on each line. On the concrete surface, each paint line passed over a strip of aluminum foil attached to the surface to provide a check on applied film thickness.

Immediately after application and before traffic was released on the site, photographs were made of the entire series of lines. A typical set of lines is shown in Figures 1 and 2. Figure 3 is a view of the test site made while data were being taken on night visibility and beta ray backscatter.

III. Preliminary Analysis of Data

In the attached "Preliminary Data Tabulation" the results on "Laboratory Abrasion Tests on Transite" have been assembled together with "Highway Test Film Integrity" at 4 weeks' exposure and "Highway Night Visibility" at 4 weeks' exposure.

The laboratory abrasion performance of the various paints is reported as a percentage of the control paint, No. 15. Individual values of duplicate and triplicate runs were tabulated to indicate the spread of these data. Where the number is followed by a plus sign it means the test was terminated before the sample had failed. The values reported for "Highway Test Film Integrity" are based on the ASTM photographic standards for abrasion (D821-47) or chipping (D913-51). With few exceptions the failure was abrasive or erosive in character. Night visibility test data were obtained in accordance with ASTM D1011-52.

The results of the laboratory abrasion tests require no further comment except in relation to the highway test data. Even at 4 weeks some loss in film integrity could be observed for most of the paints. Results conflicting with laboratory findings are indicated for some of the conventional paints, but the exceptional ruggedness of the epoxies is generally confirmed. The rating of the Epoxy-amide, No. 18, was down slightly on the highway test because this product did not dry adequately before being subjected to traffic. The Urethane, No. 17, required excessive thinning for the highway application, and the applied material cannot really be considered as representative of that which was laboratory-tested.

Among the conventional paints, the highway tests at 4 weeks show a clear superiority for Paint No. 15, Federal Specification TT-P-115-Alkyd, and Paint No. 16, Parlon-Alkyd. These paints appear outstanding in bead retention (as shown by the Night Visibility Tests) as well as in durability.

Although beta backscatter data were obtained for each of the highway test stripes, the small differences in backscatter between paint and concrete or asphalt made it impractical to attempt to estimate paint film thickness by this method.

IV. Future Program

As the highway test work matures, more reliable conclusions may be drawn about correlation with the laboratory abrasion test. Nevertheless, difficulties with the present laboratory test procedure are already quite apparent. It is planned to study a procedure of routine application of each paint at 10, 15, and 20 mils to the test panel to provide more reliable measures of wearing rates. It is also planned to begin to study various types of wetting, drying, heating, and cooling cycles with the laboratory abrader to simulate more nearly field conditions.

The potentials of certain epoxy paints for improving highway paint performance now appear so significant as to justify further attention to these materials. The suitability of epoxy resins from several sources will be evaluated and preliminary specifications for an epoxy-type highway paint will be developed.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Figure 1. Traffic Paint Test Stripes at Field Site, View I.

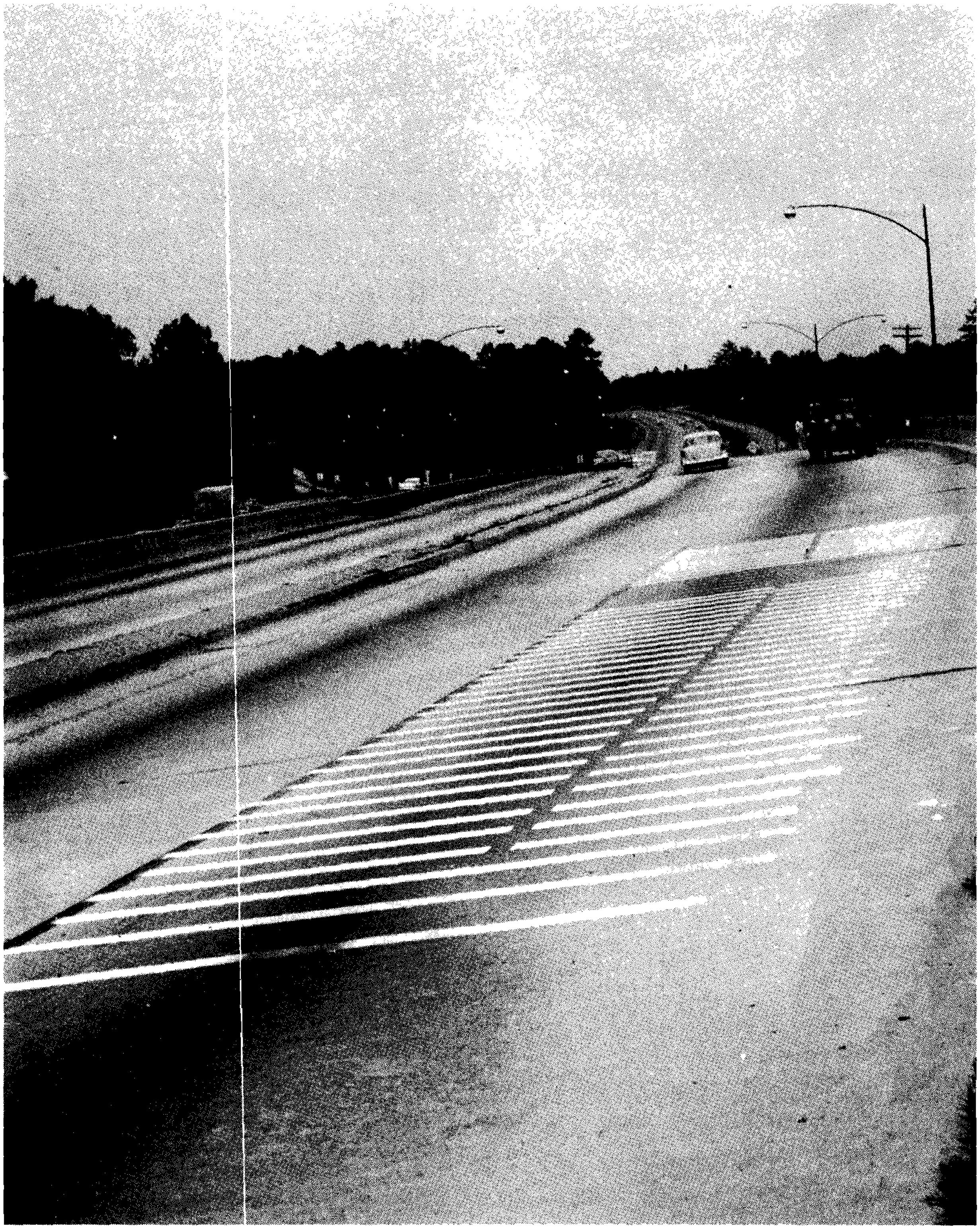

Figure 2. Traffic Paint Test Stripes at Field Site, View II.

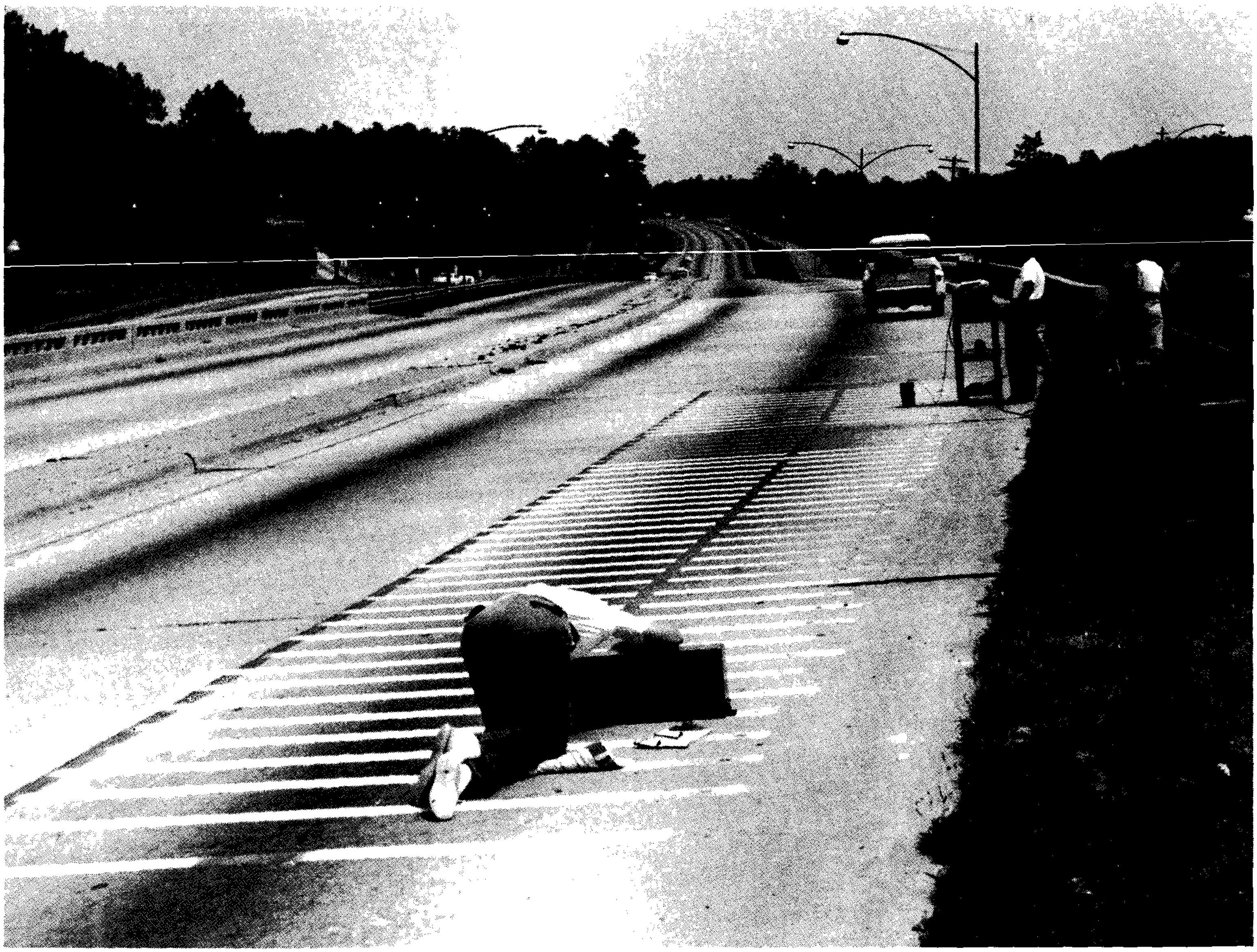

Figure 3. Night Visibility Tests and Beta Backscatter Thickness Measurements Being Made at Field Site.

PRELIMINARY DATA TABULATION

Paint Type	Pliolite		Ga. Spec.		Lacquer		Amine Epoxy		TT-P-115		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
LABORATORY ABRASION TESTS ON TRANSITE (Per Cent)																		
Dry Surface	140		100		75,130		320+		100		75,210		320+		800+,720+ 320+		800+,270+ 320+	
Wet Surface	270		270		220,100		320+		100		220,270		320+		780+,400+		780+,400+ 270	
HIGHWAY TEST FILM INTEGRITY (4 weeks)																		
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
Concrete																		
10 mils	4	5	6	6	4	4	-	-	4	5	10	9	6	8	8	8	10	10
15 "	8	8	7	9	5	5	-	-	10	10	10	10	5	8	8	8	10	10
20 "	9	8	10	8	5	5	-	-	10	10	10	10	6	7	8	8	10	10
Asphalt																		
10 mils	3	3	5	5	3	3	9	8	10	9	8	8	5	5	7	7	9	9
15 "	8	8	8	8	6	6	8	8	10	9	9	9	5	5	7	7	9	9
20 "	9	9	9	9	6	7	-	-	10	10	10	10	5	5	7	7	9	9
HIGHWAY NIGHT VISIBILITY TEST (4 weeks)																		
Concrete																		
10 mils	4	5	3	6	3	4	-	-	6	19	5	11	7	52	4	80	6	5
15 "	6	8	4	5	4	5	-	-	5	63	2	15	5	25	4	7	6	6
20 "	6	6	3	5	4	3	-	-	6	15	2	38	7	73	8	42	4	6
Asphalt																		
10 mils	5	6	4	6	4	3	4	4	5	33	3	10	3	62	14	23	3	3
15 "	8	6	5	7	2	2	4	3	4	27	2	5	3	47	10	8	2	3
20 "	6	5	5	7	2	2	-	-	4	43	2	17	2	32	7	2	2	3

*U = Unbeaded
**B = Beaded

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

January 31, 1963

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineering

Subject: Quarterly Progress Report No. 6, Project No. HPS - 1(60) Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 October 1962 through 31 December 1962.

Gentlemen:

During the period covered by this report project work has centered about the following activities:

1. Continued observation and analysis of the highway test applications.
2. Practical formulation work on an epoxy-based traffic paint, including development of suitable specifications for purchase of this type of paint.
3. Conceptual design of instrumentation to provide automatic variable cycles of heating, cooling, wetting, and drying on the laboratory abrasion tester.

Details of this work are described below.

I. Highway Test Applications

Tabulations and analysis of test data covering a period of 5 months have been completed for the group of nine experimental paints exposed on Atlanta's Northeast Expressway at Lenox Road Bridge. These applications are crosswise stripes, and since the traffic count on this road is approximately 33,000 vehicles per day, this test represents an acceleration of heavily travelled road conditions.

Observations of film integrity and of night visibility were made at one month intervals. Complete data for 5 months weathering are presented in Table I. A summary of performance results in relation to paint type, film thickness, surface type, and beading is given below.

A. Paint Type

Plots of paint integrity versus time for each experimental paint are presented in Figure 1. Integrity refers to resistance to film failure either by abrasion or chipping in accordance with ASTM D 821-47 or D 913-51. In most

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PRELIMINARY DATA TABULATION

Paint Type	Pliolite		Ga. Spec.		Lacquer		Amine Epoxy		TT-P-115		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
HIGHWAY TEST FILM INTEGRITY (5 months)																		
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
Concrete																		
10 mils	0	1	2	2	0	0	-	-	3	3	7	8	5	5	6	6	5	7
15 "	4	4	3	4	0	0	-	-	6	6	8	8	3	5	6	6	7	7
20 "	4	5	5	5	1	1	-	-	7	7	8	8	3	5	6	6	7	7
Asphalt																		
10 mils	1	1	3	3	2	2	4	3	6	6	4	4	2	3	5	5	5	4
15 "	4	4	4	4	4	4	4	5	6	6	5	5	2	2	5	4	6	6
20 "	7	7	5	5	4	4	-	-	6	7	6	6	2	2	5	4	7	7
HIGHWAY NIGHT VISIBILITY TEST (5 months)																		
Concrete																		
10 mils	1	2	2	2	2	2	-	-	3	6	3	7	5	30	4	50	6	7
15 "	2	3	1	2	2	2	-	-	5	23	3	8	4	38	4	9	10	10
20 "	3	3	2	2	2	2	-	-	5	6	3	11	6	47	8	31	10	10
Asphalt																		
10 mils	2	1	1	1	1	1	2	2	3	14	3	3	1	6	5	19	3	3
15 "	3	2	1	1	2	2	2	2	3	15	2	2	2	18	7	5	3	3
20 "	4	4	1	1	2	3	-	-	3	17	2	4	2	19	3	2	3	4

*U = Unbeaded
**B = Beaded

cases failure was by abrasion. Each point on the plot represents the average of the observations at 10, 15, and 20 mils application thickness. Separate plots are presented for beaded and unbeaded paint on concrete and on asphalt.

Plots of night visibility (ASTM D 1011-52) versus time for beaded paints are given in Figure 2. It was discovered after the test applications had been made that bead adhesion was secured only in Paint Nos. 15, 16, 17, and 18; therefore, night visibility results are confined to these items. This does not infer that the other paints are necessarily incapable of retaining beads; during the interval between the application of paint and beads the paint surface may have become too dry to adhere the beads properly.

The following observations are made concerning the individual paints:

1. The lacquer type paint (No. 13) is clearly the poorest performer in the group.
2. The Pliolite type paint (No. 6) and the Georgia specification paint (No. 11) exhibited generally similar performance, definitely below the level of the best of the "conventional" formulations.
3. A straight alkyd, TT-P-115 (No. 15) and a chlorinated rubber modified alkyd (No. 16) were among the best of the paints tested. Formulation No. 16 gave particularly outstanding integrity performance on concrete. These paints were not equal to some of the "specials", however, in maintaining night visibility.
4. Application problems were experienced with both the amine epoxy (No. 14) and the polyamide epoxy (No. 18); therefore, comparative judgments should be reserved. It is significant to note that the polyamide epoxy was second only to the urethane paint (No. 17) in retention of night visibility on concrete.
5. The retention of night visibility on concrete and asphalt by the urethane (No. 17) is particularly noteworthy. This is believed to be the first formulation of this type material ever tested on a highway. While it exhibited a tendency to chip, and was therefore not rated as superior in integrity, its resistance to abrasive wear was clearly outstanding.
6. The amine adduct epoxy (No. 19) appeared to be the most "practical" of the "special" types for actual field application. It was comparable to the chlorinated rubber alkyd in integrity, but it did not retain beads because of its very rapid drying characteristics.

B. Film Thickness

Examination of average values of integrity at 5 months weathering indicates that even at 20 mils wet film thickness the general trend toward improvement of durability with increasing film thickness does not level off. This trend is shown in Figure 3. Statistically, the differences among the various averages is of doubtful significance. Note, however, that the average values for paints on concrete and for beaded paints both lie above the overall average line.

Night visibility at 5 months versus film thickness for those paints which retained beads is shown in Figure 4. In this case the line for paints on concrete is significantly higher than the overall average, but the trend toward improvement with increasing film thickness is absent. The probable reason for this may be more apparent from the data represented in Figure 5.

Figure 5 is a plot of integrity versus film thickness for the individual paints at 5 months weathering. Note that, with the exception of No. 15, those beaded paints which comprised the data for Figure 4 (Nos. 15, 16, 17, and 18), do not show an upward trend of integrity with increasing film thickness. This observation is consistent with the previously observed superior integrity of these paints. In other words, in the range of film thickness studied, the more durable paints exhibit a relatively constant high level of integrity, and performance does not improve with increasing film thickness. This is, of course, in distinct contrast to the decidedly positive response of the less durable paints to increasing film thickness.

C. Surface Type

The data presented in Figures 1 through 5 clearly show an average superior performance for paints on concrete rather than asphalt. This is definitely not in agreement with historical experience on this subject.* An inspection of Figure 1, however, shows that the "conventional" paints (Nos. 6, 11, 13, 15) do, indeed, follow the classical pattern of better performance on asphalt. It is the "special" paints which have reversed the pattern and weighted the averages. It is assumed that the superior adhesive and cohesive properties of these paints enable them to utilize the more stable characteristics of the concrete substrate. These "special" vehicles may even permeate the concrete surface and serve as a binder or hardener to produce a more stable substrate.

D. Beading

Much of this subject has been covered in the preceding discussions. The following points deserve emphasis:

1. Superior bead retention, as measured by night visibility, was exhibited by the "special" paints, and particularly by the polyurethane (No. 17).
2. Bead retention on concrete was superior to that on asphalt, for the limited group studied.
3. Specific conclusions about bead retention and its effect on durability for most of the paints is not possible, since in most cases it was evident that the beads must have been applied to semi-dried paint stripes.

II. Epoxy-Based Traffic Paint Formulations

The extremely superior abrasion resistance of experimental epoxy traffic paints as measured on the laboratory abrasion tester was noted in the previous quarterly report. These data, together with early findings of good performance

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*W. H. Goetz, "Field and Laboratory Investigation of Traffic Paints," Proceedings, Highway Research Board 21, 233-259 (1941).

in the highway test applications, confirmed a decision to proceed with further investigation of the epoxies.

A white, epoxy resin base traffic paint, developed by one of the manufacturers of epoxy resins, was selected as the basis for this work. This formulation utilized a blend of two resins having melting points of 65-75°C, and 125-135°C. The epoxide equivalents were 425-550 and 2000-2500, respectively. The paint used for the highway tests was furnished by this manufacturer and exhibited excellent application characteristics. This manufacturer also reported independent highway test results on this formulation.

It was concluded that this formulation had sufficient merit and practicality to justify development of specifications that would permit it to be purchased from regular vendors for large scale tests. Tentative specifications were drafted. Since several epoxy resin manufacturers had cooperated with the project, it was decided that appropriate epoxy resins from several sources would be tested and approved for this use.

Technical information and samples were obtained from the above manufacturer and four other manufacturers of epoxy resins. It was intended that the paint would be prepared in laboratory batches from each manufacturer's resins and that all which proved satisfactory in laboratory tests would be approved for vendors' use. Here a completely unexpected difficulty was encountered. When the paints were prepared, none exhibited satisfactory consistency properties. Our preparation of the formulation described above was extremely thixotropic or "puffy" -- entirely different in characteristics from the paint sample received from the manufacturer. At the date of this report the problem is still unresolved despite several long distance calls to the manufacturer's laboratories, much experimentation, inquiry among paint technologists, and pertinent literature study. The source of this difficulty will be located; however, the program has been delayed and the issue of suitable specifications must await the findings of this work.

Notwithstanding this particular problem, the epoxy resins have clearly demonstrated interesting durability potentials, and continued concentrated work on these materials has been planned.

III. Laboratory Abrasion Testing

In the previous report (No. 5 dated October 22, 1962) poor correlation between laboratory abrasion tests and highway paint performance was indicated. Now after 5 months of highway exposure, the situation is not appreciably changed. It seems apparent that the laboratory tester, as it has been operated, exaggerates the abrasion factor of wear and ignores other important durability factors.

Observations on the highway suggest that one important factor is the nature of the substrate. Aggregate particles at or near the surface create a roughness, and cause significant variations in surface porosity. Under these conditions, adhesion and resistance to shearing forces are undoubtedly very important. In our work with concrete discs on the laboratory machine these effects were evident. Unfortunately, we were unable to produce trowelled surfaces with satisfactory uniformity. The relatively gross nonuniformity of the surface, as compared with the size of test area, tended to produce very erratic results. On the other hand, the transite surfaces used for most of the test work were very smooth and uniform; thus they may have failed to give adequate weight to shear and adhesion factors.

To attain a more suitable substrate, experimentation will be directed toward developing a grinding technique to produce a flat aggregate-studded surface of concrete. By thus eliminating gross nonuniformities, but retaining the aggregate effects, more representative results should be attainable.

Further substantial improvements of this test should be realized by installation of apparatus and controls on the machine to provide cycling of the environmental conditions of heating, cooling, wetting and drying. An economical assembly to accomplish these cycles automatically is being designed.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

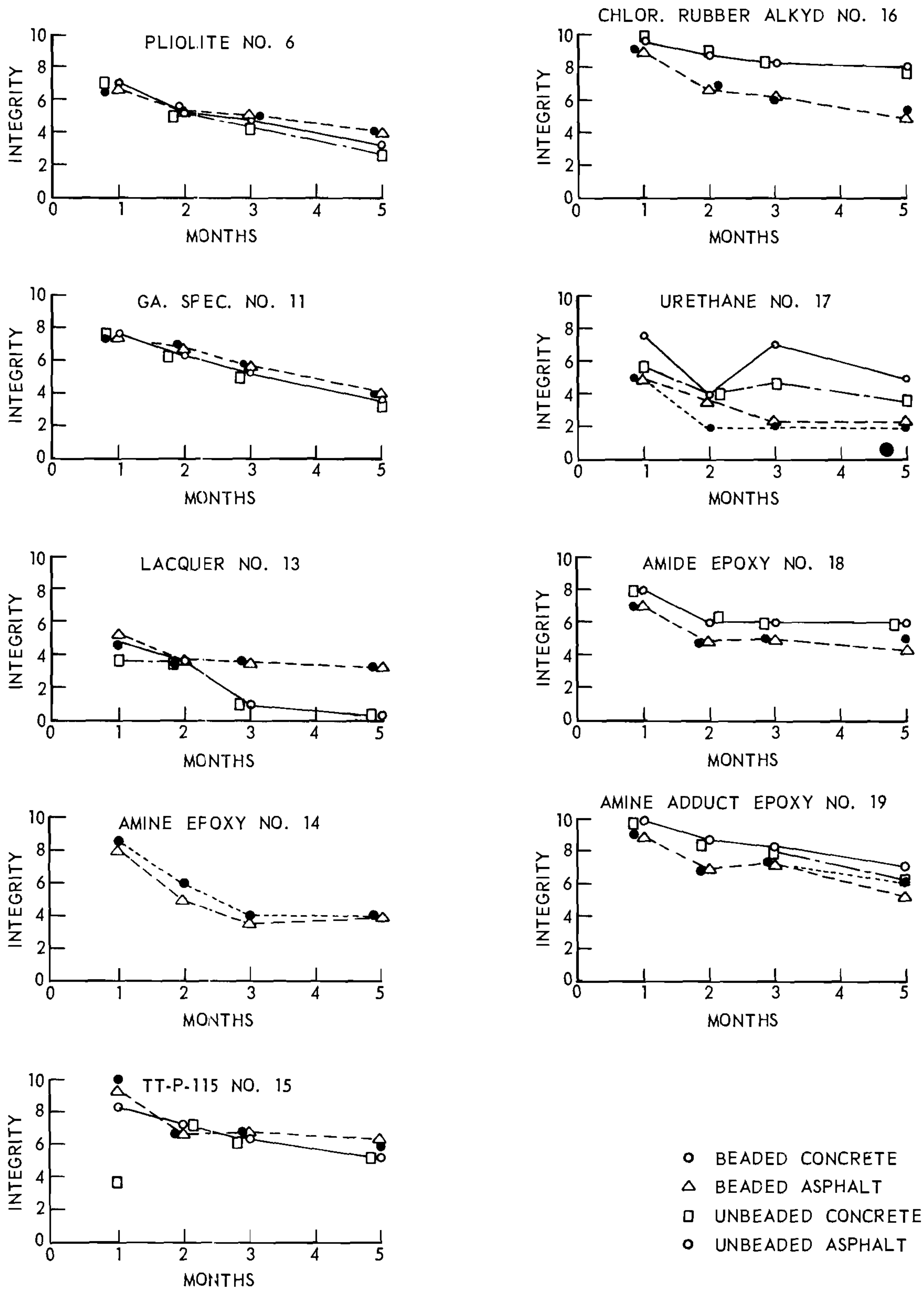

Figure 1. Paint Integrity Versus Exposure Time.

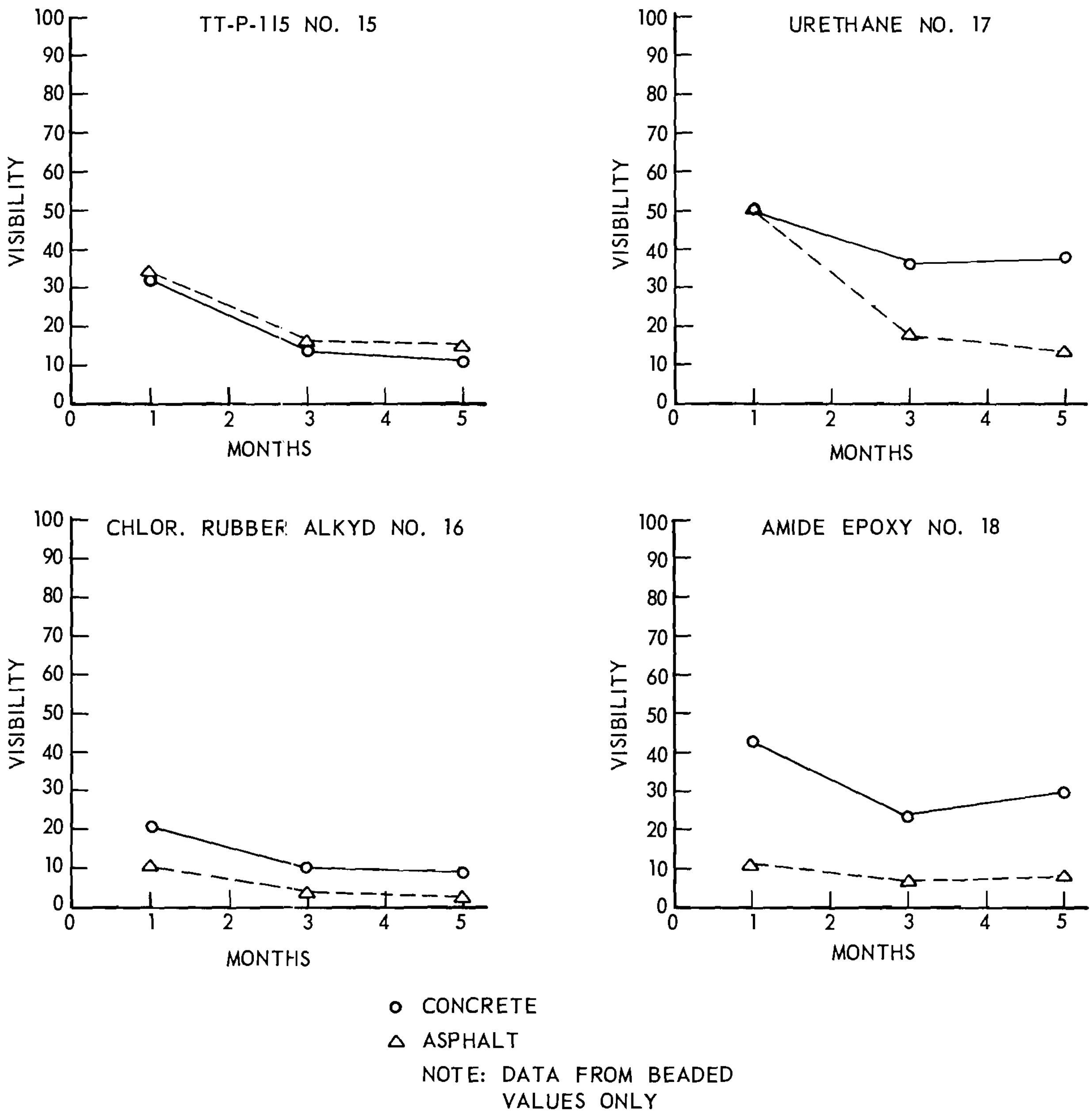

Figure 2. Night Visibility Versus Exposure Time.

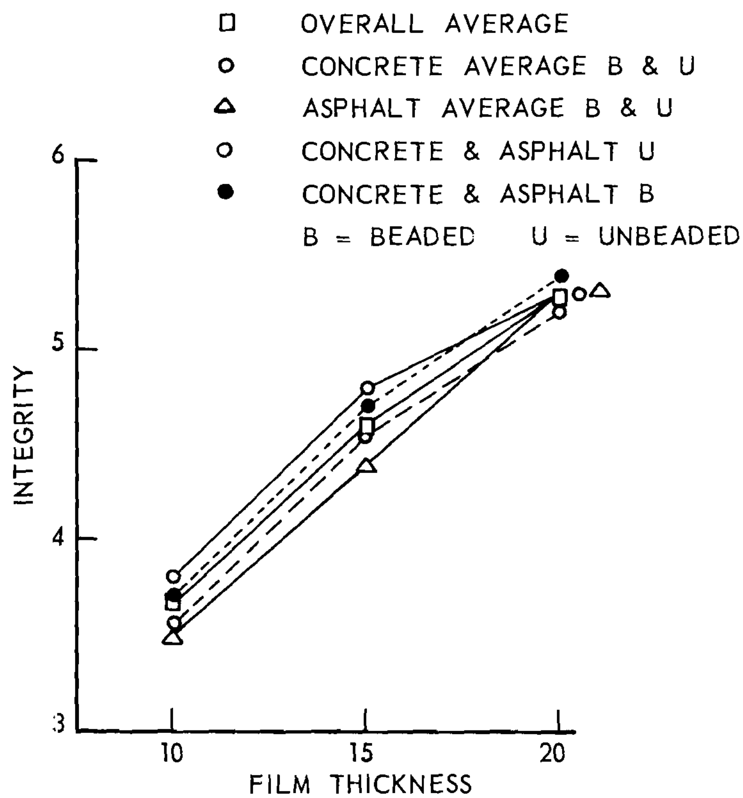

Figure 3. Average Integrity Values Versus Film Thickness at Five Months Exposure.

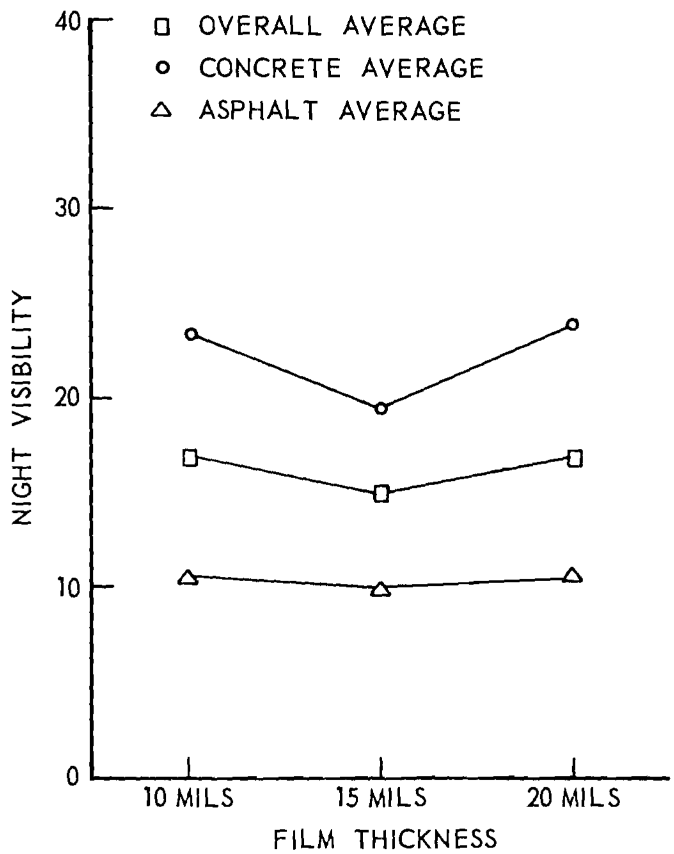

Figure 4. Night Visibility Versus Film Thickness at Five Month Exposure for Paints 15, 16, 17, and 18, Beaded Stripes Only.

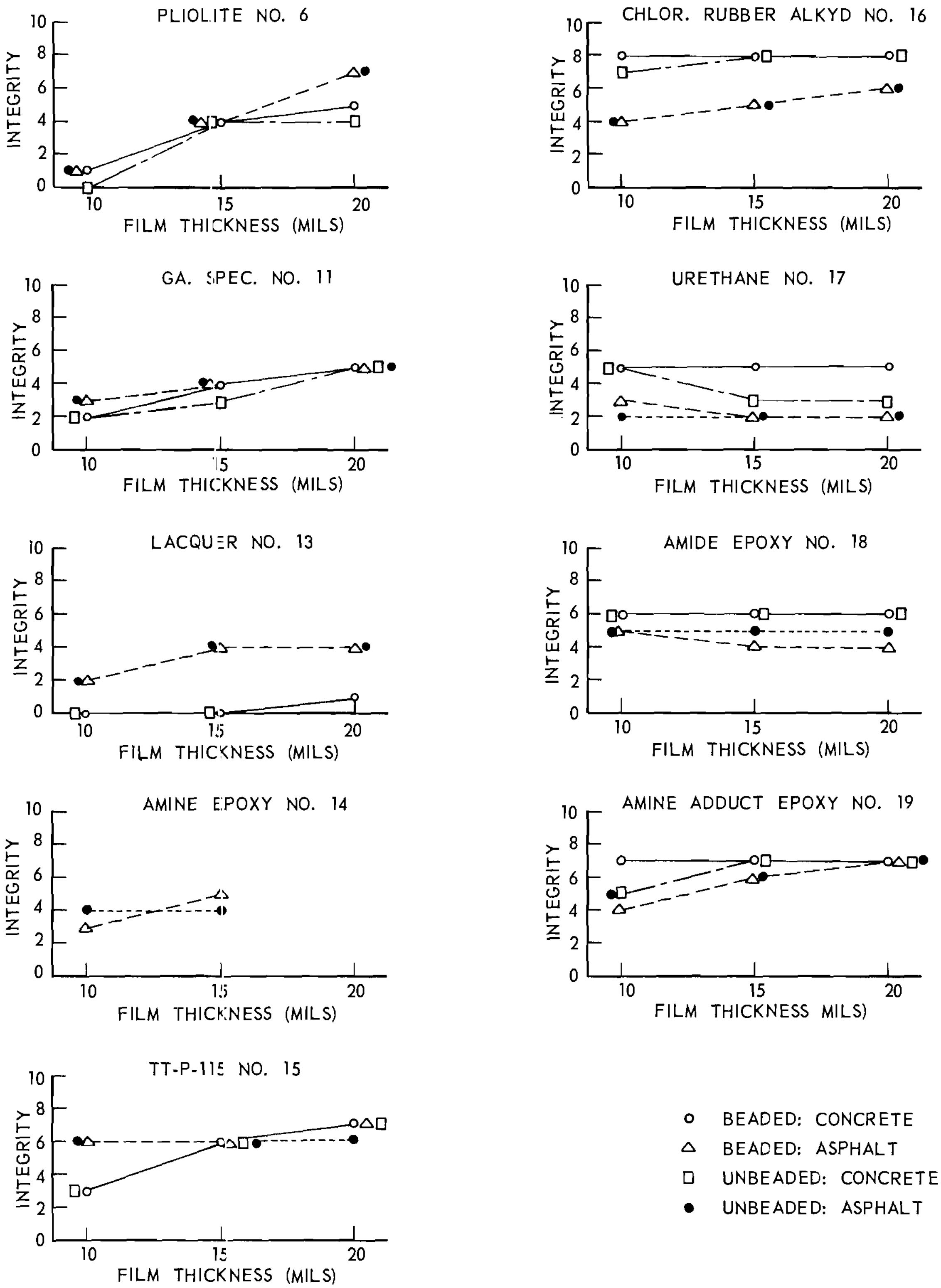

Figure 5. Individual Paint Integrity Value Versus Film Thickness at Five Months Exposure.

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ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

July 26, 1963

MAY 1969

State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineering

Subject: Quarterly Progress Report No. ~~8~~ 7, Project No. HPS - 1 (60) Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 April 1963 through 30 June 1963.

Gentlemen:

Project activities during the period covered by this report are summarized as follows:

1. Continued observation and analysis of the highway test applications.

2. Additional formulation work on "conventional" and "special" type traffic paints with emphasis on a practical specification for a polyamine catalyzed epoxy type.

3. Completion of modifications of the laboratory wear tester and initiation of tests thereon.

I. Highway Test Applications

A detailed analysis of the trends of the highway test data was presented in Progress Report No. 6 for 5 months of weathering. A comprehensive analysis will be deferred until the data for 1 year are obtained in August.

The following summary of the 9 months of observations up to May is given.

A. Paint No. 16 (chlorinated rubber modified alkyd) continues to exhibit outstanding durability. Reflectance retention is not quite equal to some of the "specials."

B. Paint No. 15 (straight alkyd) shows an average durability of 5, about three points below No. 16, but its reflectance retention is slightly better.

C. The "specials" now show poorer durability than No. 16, but definitely superior reflectance retention.

D. Paint Nos. 6, 11, and 13 are now definitely "out of the running."

The asphalt section of tests was covered with repaving in May, 1963; therefore, this portion of the test is concluded. Since a very good performance spread had been developed among the test items at 9 months, this loss of the test section should not seriously affect the conclusions. Photographs were made at 9 months, and another set will be made at 12 months on concrete.

Subject to satisfactory progress on formulation work discussed in the next section, plans have been developed to initiate a second series of highway tests in August. This will be a shorter series and will involve only beaded stripes. The beading device is to be attached directly to the striper this time to correct the previous problem of paint predrying and resultant poor bead retention.

II. Formulation Work

The problem of puffiness of the polyamine-epoxy has been solved, and laboratory wear testing of four commercially available resin-catalyst systems is nearing completion. Preliminary results indicate that at least three of these systems can be approved for use in a Tentative Epoxy-Type Traffic Paint Specification.

Despite outstanding results in the field with the chlorinated rubber alkyd, an indication of slight, early chipping discouraged too much enthusiasm for this system. The cause and correction of this problem is another current job. If a specific cause is not uncovered, we propose to lower the PVC to the level of the straight alkyd for retesting.

The polyurethane is being studied in an effort to improve shelf stability and correct a definite chipping tendency. The TDI (tolylene diisocyanate)concentration has been stepped up in the slurry grind to assure neutralization of all reactivity in the pigmentation. We have modified the polyurethane vehicle by blending with a similar polymer of greater flexibility. These changes may correct previous difficulties.

Recently we have been favorably impressed by evidence furnished us from field testing of certain types of hot melt compositions. Most interesting is the fact that compositions of good durability are sufficiently economical in cost to permit consideration of a "turn-pike" or crowned configuration of a center stripe. This could provide an effective approach to the problem of visibility on wet nights. Presumably, the crown would drain the water off of the stripe and thus greatly reduce the light-quenching effect of the water. Materials have been ordered.

The next series of highway tests will include:

1. Straight alkyd (Paint No. 15 as a control against prior year's tests).

2. Georgia Highway Department Tentative Spec. No. 5 (alkyd).

3. New chlorinated rubber-alkyd.

4. New polyurethane.

5. Hot melt composition.

6. Epoxy-polyamide (if available in time).

III. Laboratory Wear Testing

The modifications to the laboratory wear tester were completed during the first month of this report period. A photograph of the tester in its present form is shown in Figure 1. The large box at the upper left on the apparatus is an insulated ice water reservoir. Application of cold water to the test panel is controlled by a timer-solenoid arrangement. The pair of sunlamps above the test disc are capable of providing intense ultraviolet and heat irradiation. A feature not shown in the photograph is a long T-bar attached to the rear of the abrader wheel frame. This bar can be loaded with weights to vary the bearing pressure on the abrader wheel. It appears probable that wheel pressure must be reduced from the original level as a means of extending the length of the test period to give proper effect to the wetting-drying, heating-cooling cycles and the accumulation of irradiation degradation.

The control panel on the front of the machine contains a running time meter, a cycle counter, control switches, and pilot lamps. Space is provided also for two cycle timers which are to be installed as soon as the requirements are experimentally determined. (The water timer has been ordered.)

Since two types of new variables are embodied in the new machine (test panel facing, and new operating variables), it appeared desirable first to evaluate the effects of the new type of surface. Accordingly, a set of three panels was prepared at nominal 10, 15, and 20 mils wet films with the following paints.

No. 11 - Georgia Specification
No. 15 - Alkyd
No. 16 - Chlorinated Rubber Alkyd
No. 19 - Polyamine-Epoxy

These panels were tested in the usual fashion: dry. Figure 2 shows the appearance of the panels after testing. Figure 3 is a plot of the performance of each paint in terms of "cycles to failure," where failure is defined as a rating of 4 on ASTM:D821-47 Abrasion. Some difficulty was encountered in attaining the desired uniform spread of film thickness. Application technique has been improved recently, however. Some of the data show undesirable scattering. It was found that this is caused to a substantial extent by a slight up and down oscillation of the concrete disc as it rotates. This oscillation presents some of the painted sections to the abrader wheel at a slight angle from true 90° and imposes uneven wear which is difficult to evaluate in comparison with even wear on the other sections. This problem has since been solved by putting a disc-leveling device on the turntable, and truing up each disc with a feeler gage before running a test.

Notwithstanding these problems, the wear on the new panels is seen to be very superior in uniformity to that obtained in earlier work. For example, Figure 2 may be compared with tests on transite and troweled concrete as shown in Figure 6 of Report No. 3, p. 13.

Returning now to Figure 3, if we choose a nominal wet film thickness of 15 mils to report test results, then the performance of the test paints is as follows:

Paint No.	Cycles
11	13,800
15	17,500
16	30,300
19	24,500

Reference to prior work (see Annual Report No. 2, p. 15, Tables III and IV; and p. 30, Figure 8) indicates that these results correlate well with highway test data. This is most encouraging, of course, but until we confirm the findings repeatedly with a broader selection of paints we shall reserve any final conclusions. Certainly this "dry" wear test cannot be as representative of the field environment as the cycling tests which will receive study in the immediate future.

Following the foregoing work, a series of similar tests was run to study the performance of polyamine epoxy materials from four different suppliers. Consistent performance differences were observed. Results of this work will be given in a subsequent report.

IV. Future Work

Intensive preparation for the new highway test series is now in progress and will probably continue well into August.

As soon as possible, the study of environmental variables will begin on the laboratory wear tester and will occupy primary attention.

Additional formulation studies will be carried forward in parallel at a lower priority level.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

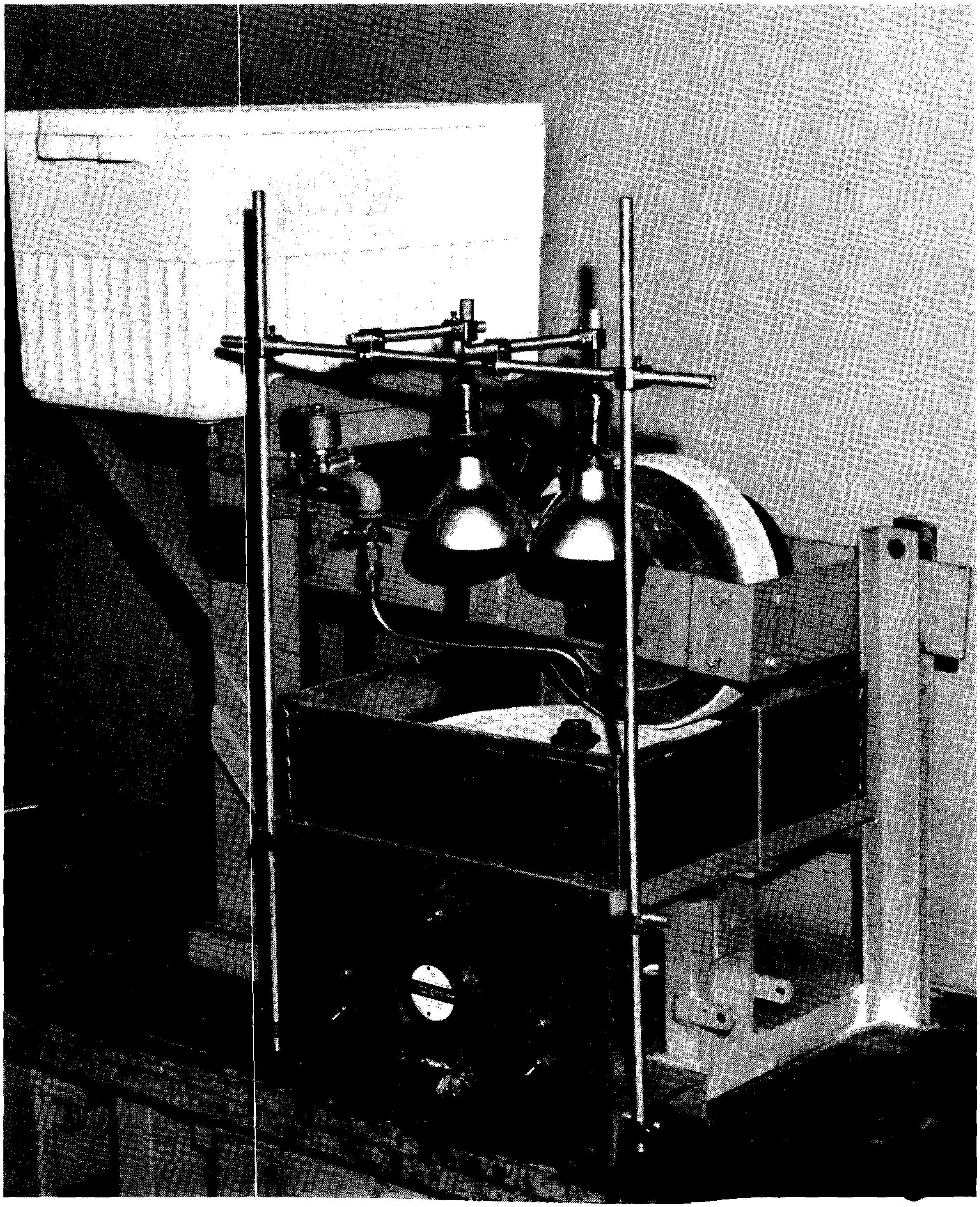

Figure 1. Modified Wear Test Machine.

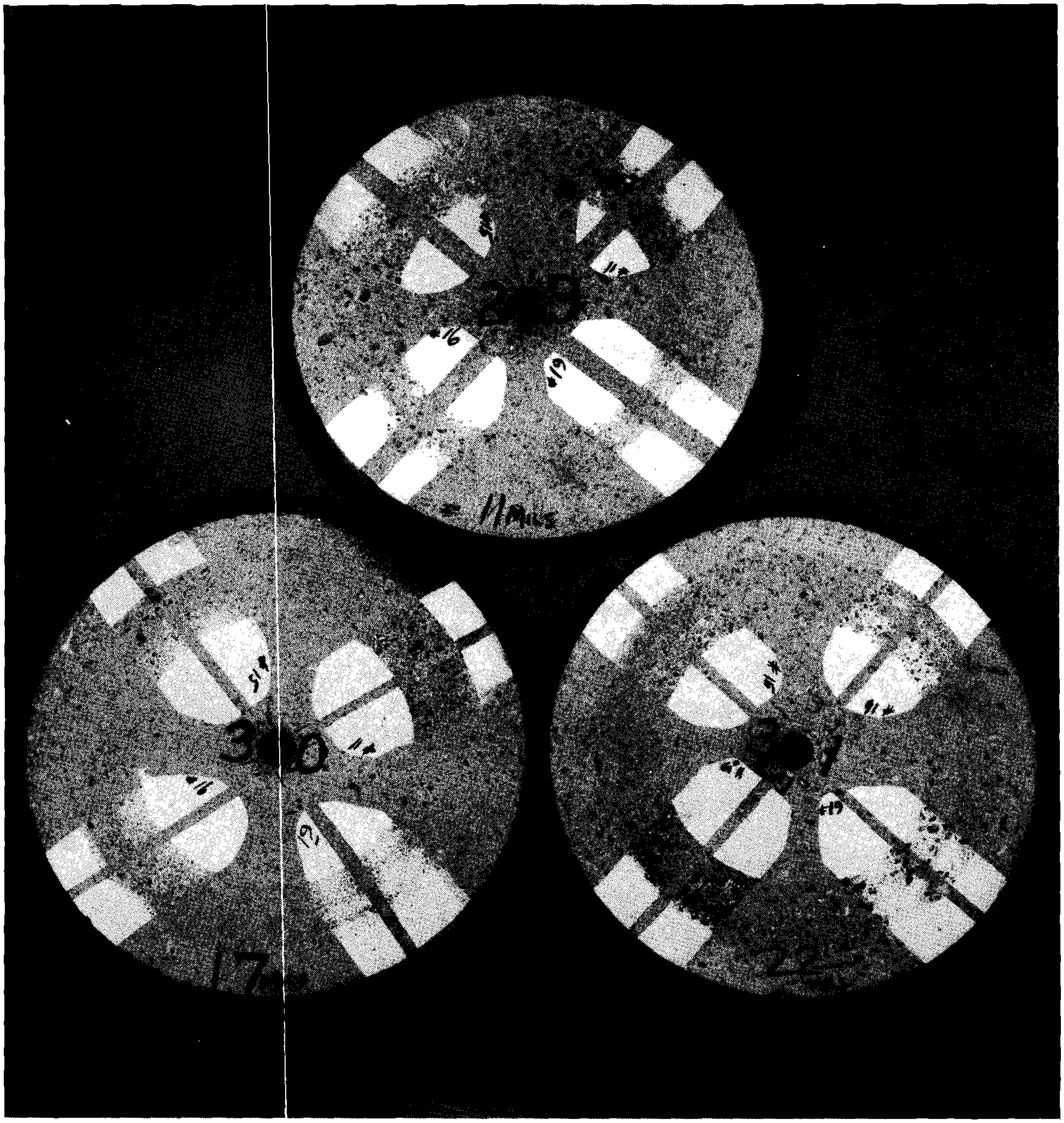

Figure 2. Wear Test Panels After Testing.

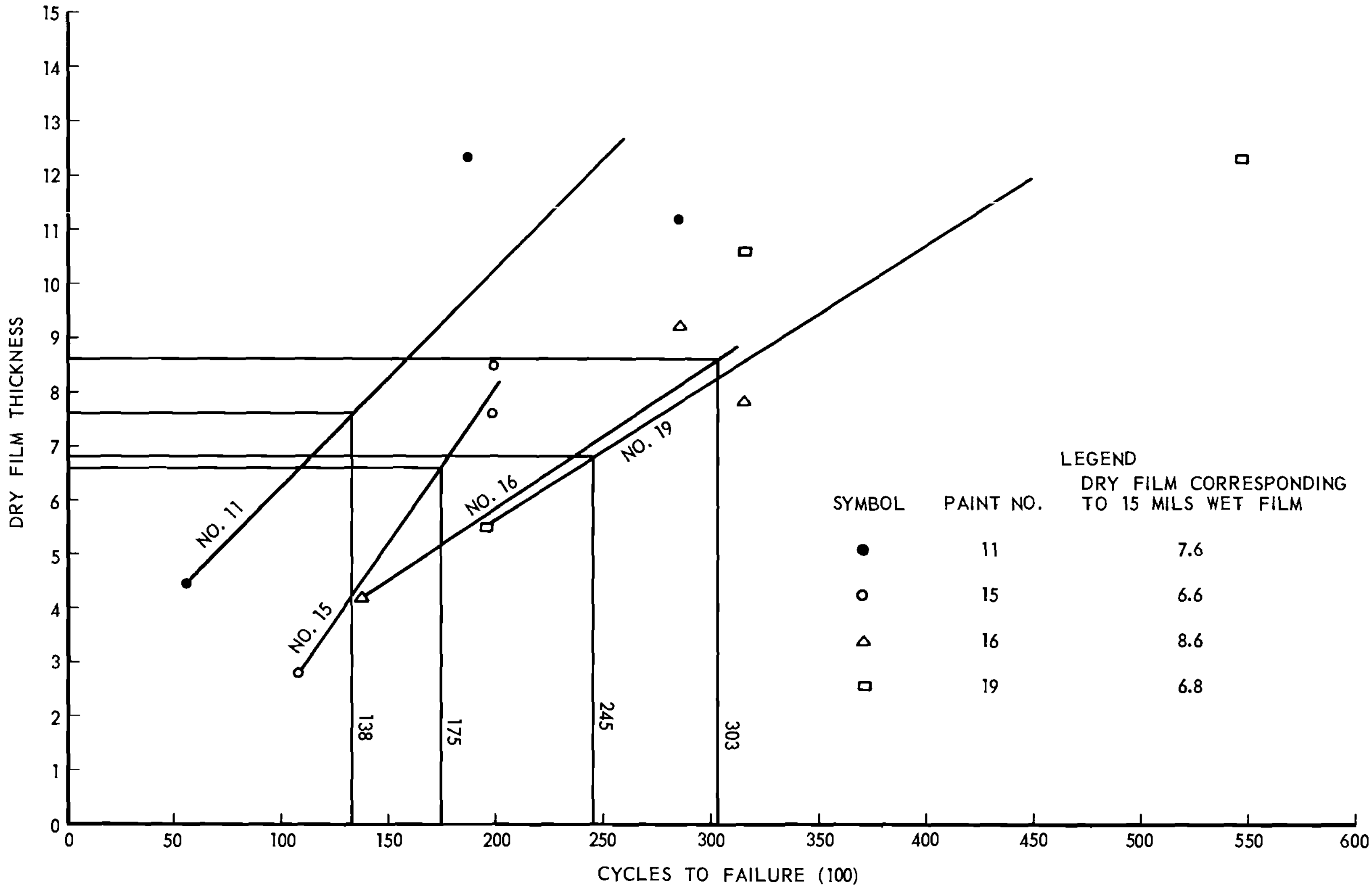

Figure 3. Accelerated Wear Testing.

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineering

Subject: Quarterly Progress Report No. 8, Project No. HPS - 1 (60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 July 1963 through 30 September 1963.

Gentlemen:

Project activities during the period covered by this report are summarized as follows:

1. Observation of first series of highway test stripes at one year's service, and preparation work on a special report on this subject.
2. Application of a second series of highway test stripes.
3. Continued work on modified wear test machine.
4. Analysis of findings on epoxy formulations.

Additional details follow.

I. Highway Tests, Series I.

On August 1, 1963, one year from the time of application, the highway cross-stripe tests on the Atlanta Northeast Expressway at the Lenox Road Bridge were inspected and photographed. One year of service under the conditions of extremely heavy traffic existing at this site has been fully sufficient to establish the relative performance of each test paint. The relations of film thickness to paint performance have also been quantitatively demonstrated. A special report on these tests is in preparation; therefore, only the most significant conclusions are summarized below:

1. Among "conventional" paint types tested, alkyd and alkyd-chlorinated rubber formulations demonstrated distinct superiority.
2. "Special" paints based on epoxies and polyurethanes exhibit certain interesting properties (notably superior bead retention), but are not presently "field-practical."
3. The improvement of paint durability with increasing film thickness will usually justify the application of a wet film of 20 mils.

II. Highway Tests, Series II

On September 3, 1963, a second series of highway cross-stripe tests was applied to the concrete roadway immediately south of the first series. These tests involved five paint formulations, each applied at 10, 15 and 20 mils wet with all stripes beaded. The bead applicator was attached directly to the painting machine for these tests, so that bead retention would not be affected by partial drying of the paint film before application of beads, a difficulty which had limited some conclusions from Series I.

The paints for Series II are described as follows:

Formulation No.	Description
15	Alkyd, linseed, 30% P.A.
29	Alkyd, formulated to minimum Georgia Specifications
36	Chlorinated rubber modified alkyd, 50% P.V.C.
37	Epoxy-polyamide
38	Epoxy-amine adduct

Complete formulation data sheets for each of the above paints are attached with this report. Formulation No. 15 is a "control" paint, identical with the same item from Series I. No. 29 is prepared to be representative of the quality that may be furnished by vendors to meet Georgia Highway Dept., Tentative Maintenance Specification No. 4. No. 36 is an approach to further improvement in the formulation of this chlorinated rubber modified type (No. 16) studied in Series I. No. 37 is a major revision in the epoxy-polyamide studied in Series I. The earlier formulation (No. 18) depended upon resin reaction to achieve drying; the new formulation is of a lacquer-drying type. Formulation No. 38 is a slight modification of No. 19 from Series I.

It was not feasible to include in this new series several items that were originally felt to be of interest. A moisture-cured polyurethane formulation could not be included because of very poor can stability. Attempts to achieve a satisfactory hot melt composition based on plasticized sulfur were not advanced sufficiently to justify field testing. These and other studies of new materials will be continued in the laboratory.

III. Modified Wear Test Machine - Epoxy Formulations

Prior reports have mentioned an intention to develop tentative specifications for traffic paints based on amine adduct catalyzed epoxy resins. In furtherance of this intention paints based on four candidate brands of epoxy resins were subjected to accelerated wear testing. These tests were run exactly as described in the last quarterly report (No. 7) without utilizing the recently added water and heat cycling features. The results of this set of tests, in terms of cycles to failure for nominal 15 mil wet films, are given below:

Paint No.	Resin	Cycles to Failure
30	S	33,900
31	D	29,200
32	C	27,300
33	R	31,800

This set of tests, together with similar tests detailed in Quarterly Report No. 7 and current results from Highway Series I, has required a re-evaluation of earlier evidence of the special merits of the catalyzed epoxy paints included in the program to date. It was recognized initially that the systems that appeared to be the very best in durability characteristics were not field-practical because of slow drying characteristics. The faster drying modification that has now been tested both in the laboratory and the field does exhibit good performance. However, it is not sufficiently outstanding to justify its premium cost and the disadvantages of a two-component system. Accordingly, the preparation of tentative specifications covering this type of paint has been deferred, and further studies of special vehicle resins are being continued.

IV. Current and Future Work

Experimental studies of operating variables with the modified wear tester have been in progress, and a tentative standard cycle has been established. This work is scheduled to proceed continuously. When it appears that the accelerated test is approaching reproducible correlation with the field data, then comprehensive, designed experiments will be undertaken to develop detailed knowledge of main effects and interactions of the controlled variables. Planned simulation of various climatic conditions may then be feasible.

Respectfully submitted,

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 15

TT - P - 115, white

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams	
PIGMENT	48.0	21.2					
Rutile 610 - TiO_2	29.8	20.8	150	35.0	4.3	680	
Gamaco	29.8	32.4	150	22.6	6.7	680	
Celite 281	19.8	25.1	100	19.2	5.2	454	
Nytal 300	19.8	20.3	100	23.8	4.2	454	
Bentone 38	0.8	1.4	4	15.0	0.3	18	
	100.0	100.0	---		---	---	
			504		20.7	2286	
VEHICLE	52.0	78.8					
Alkyd P 670-55	69.1	65.8	377	7.5	50.3	1710	
VM & P Naphtha	28.2	32.0	154	6.3	24.5	700	
Cobalt Naphth. - 6%	0.5	0.5	3.0	8.0	0.4	13.6	
Lead Naphth. - 24%	1.4	1.0	7.5	9.6	0.8	34	
Mn Naphth. - 6%	0.2	0.3	1.0	8.1	0.2	4.5	
Adv. Anti-skin agent	0.6	0.5	3.5	7.8	0.4	15.9	
			546.0		76.6	2478.0	
	100.0	100.1	1050		97.3	4764.0	

WEIGHT PER GALLON 10.8 LBS.

200g VM % P used for grinding

P.V.C. 48.0 %

TOTAL SOLIDS:

WEIGHT 68.1 %

VOLUME 44.3 %

Project No. B-210

Date 3/7/63

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 29

Ga. Tentative Specification #4

White Traffic Line Paint

	% WEIGHT	% VOLUME	100 GALLON BATCH			
PIGMENT	50.0	20.3	Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
Rutile 610 TiO_2	28.4	6.7	142	35.0	1.2	645
Gamaco	30.0	37.1	150	22.6	6.6	681
Celite 281	20.8	30.3	104	19.2	5.4	472
Nytal 300	20.8	23.6	100	23.8	4.2	454
Al. Stearate	0.8	2.2	4	10.0	0.4	18
	100.0	100.0	500		17.8	
VEHICLE	50.0	79.7				
Alkyd P 670-55	73.0	70.1	365	7.5	48.7	1657
V M & P Naphtha	24.3	27.8	121.5	6.3	19.3	552
Cobalt Naphth. - 6%	0.5	0.4	2.5	8.0	0.3	11.4
Lead Naphth. - 24%	1.4	1.0	7.0	9.6	0.7	32
Mn Naphth. - 6%	0.2	0.1	1.0	8.1	0.1	4.5
Adv. anti-skin agent	0.6	0.6	3.0	7.8	0.4	13.6
			500.0		69.5	
	100.0	100.0	1000.0		87.5	

WEIGHT PER GALLON 11.4 LBS.

P.V.C. 45.4 %

TOTAL SOLIDS:

WEIGHT 70.3 %

VOLUME 44.8 %

Project No. B-210

Date 7/25/63

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 36

Parlin Alkyd Traffic Paint, White

	% WEIGHT	% VOLUME	GALLON BATCH			
			Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	53.2	27.3				
Rutile - 610 TiO_2	24.4	16.9	180	35.0	5.14	817
Gamaco	54.8	58.9	405	22.6	17.92	1839
Nytal 300	10.1	10.5	75	23.6	3.18	340
Celite 281	10.1	12.9	75	19.2	3.91	340
Bentone 38	0.5	0.9	4	15.0	0.27	18
	99.9	100.1	739		30.42	3354
VEHICLE	46.8	72.7				
Parlon S-10, 30% in toluene						
Parlon S-10	8.9	5.3	58	13.6	4.26	263
Toluene	20.8	23.0	135	7.25	18.62	613
Alkyd P-296-70	55.2	55.2	358	8.0	44.75	1625
Toluene	13.6	15.0	88	7.25	12.14	400
Propylene Oxide	0.6	0.7	4	7.5	0.53	18
Cobalt Naphth. - 6%	0.3	0.3	2	8.0	0.25	9
Adv. anti-skin agent	0.6	0.6	4	7.8	0.51	18
			649		81.06	2946
	100.0	100.1	1388		111.48	6300

WEIGHT PER GALLON 12.45 LBS.

P.V.C. 49.8 %

TOTAL SOLIDS:

WEIGHT 76.2 %

VOLUME 54.8 %

Project No. B-210

Date 8/30/63

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 37

Epoxy Polyamide Traffic Paint, White

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams	
PIGMENT	57.3	30.1					
Rutile 610 - TiO_2	30.5	21.4	200	35.0	5.71	908	
Gamaco	30.5	33.2	200	22.6	8.86	908	
Nytal 300	19.1	19.7	125	23.8	5.25	568	
Celite 281	19.1	24.4	125	19.2	6.51	568	
Bentone 38	0.8	1.2	5	15.0	.33	23	
	100.0	99.9	655		26.66	2975	
VEHICLE	42.7	69.9					
Versamid 125	20.5	19.4	100	8.3	12.05	454	
Toluene	10.2	11.1	50	7.25	6.90	227	
Acetone	20.5	24.4	100	6.6	15.15	454	
Methyl Isobutyl Ketone	10.2	12.0	50	6.7	7.46	227	

EPON 1001-A-80	38.5	33.0	188	9.2	20.43	854	
			488		61.99	2216	
	99.9	99.9	1143		88.65	5191	

Total solvents used for grinding.

20 grams curing agent for 100 grams ingredients.

WEIGHT PER GALLON 12.89 LBS.

P.V.C. 49.5 %

TOTAL SOLIDS:

WEIGHT 79.2 %

VOLUME 60.8 %

Project No. B-210

Date 8/16/63

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 39

Epoxy Amine Adduct Traffic Paint, White

		% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
	PIGMENT	49.3	23.5					
	Rutile - 610 TiO_2	29.4	20.5	175	35.0	5.00	795	
	Gamaco	29.4	31.8	175	22.6	7.74	795	
	Celite 281	20.2	25.7	120	19.2	6.25	545	
	Nytal 300	20.2	20.7	120	23.8	5.04	545	
	Bentone 38	0.8	1.4	5	15.0	.33	23	
		100.0	100.1	595		24.36	2703	
	VEHICLE	50.7	76.5					
	EPON 1001-A-80	20.5	16.9	125	9.3	13.44	568	
	EPON 1007-CT-55	29.8	27.3	182	8.4	21.67	826	
25%	Toluene	11.5	12.2	70	7.25	9.66	318	
50%	Acetone	22.9	26.7	140	6.6	21.21	636	
25%	Methyl Isobutyl Ketone	11.5	13.1	70	6.7	10.45	318	
	Curing Agent U	2.0	1.8	12	8.5	1.41	55	
	Toluene	2.0	2.1	12	7.25	1.66	55	
				611		79.50	2776	
		100.2	100.1	1206		103.86	5479	

WEIGHT PER GALLON 11.61 LBS.

P.V.C. 52.9 %

TOTAL SOLIDS:

WEIGHT 66.9 %

VOLUME 44.4 %

775 grams composite solvent used for grinding.

1 gram curing agent for 100 grams ingredients.

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

February 3, 1964

1969

State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. Roy A. Flynt
State Highway Planning Engineer

Subject: Quarterly Progress Report No. 9, Project No. HPS - 1 (60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 October 1963 through 31 December 1963.

Gentlemen:

During the subject period research has been conducted in the following areas:

I. Highway test stripe observations.

A. Series I (applied 8/1/62.)
B. Series II (applied 9/3/63.)

II. Accelerated wear test development.

A. Construction of special reflectometer.
B. Further development of test procedures.
C. Current work and plans.

III. Formulation Studies

A further appreciation and understanding of the joint effects of paint film thickness and beading on paint performance is perhaps the most significant single experimental finding developed during the current project period.

A more detailed summary of project activity follows:

I. Highway Test Observation

A. Series I (applied 8/1/62).

A special report on this study is to be issued following 18 month field observations to be made early in February. The outstanding durability of Paint

REVIEW
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No. 15 (alkyd) and Paint No. 16 (chlorinated rubber modified alkyd) continues to be the most outstanding finding from this work. Unfortunately, the value of this study is impaired somewhat by the fact that the beading technique was not representative of actual field practice. The lapse of several minutes between application of paint and the beading operation is now believed to have exerted a distinctly detrimental effect on the bead holding capabilities of most of the formulations tested.

B. Series II (applied 9/3/63).

Details of formulation and application of this test series were presented in Progress Report No. 8. The test stripes were inspected at one month and at three months following application. Performance observations made at these inspections are presented in Table I. Photographs of the complete series initially and at three months' wearing are shown in Figure 1.

One of the most apparent observations from Table I is the very significant response of both film integrity and night visibility to increasing film thickness. This effect is seen even more clearly in Table II, where differences between twenty mil and ten mil films have been tabulated. The performance superiority of a twenty mil film would appear to justify the additional thickness even when compared with films of fifteen mils, as indicated in Table III.

A more detailed discussion of the relative performance of the various paint formulations will be presented in subsequent reports as more mature data are acquired. However, it is already obvious that Paint No. 37 (epoxy-polyamide) and Paint No. 29 (alkyd, min. spec.) exhibit a combination of superior film integrity and night visibility at three months' wear.

II. Accelerated Wear Testing

A. Construction of Special Reflectometer

An instrument suitable for measuring bead retention or night visibility on accelerated test panels has been a recognized need of this project for a long time. While the project has on loan from the Georgia State Highway Department a model of the Hunter Night Visibility Meter, this large instrument cannot be used on the small painted area of the accelerated test panels. The fact that no commercial meter could be adapted to the needed measurement led to a decision to construct an instrument.

The design criterion for the new instrument was simply that it should be capable of measuring the intensity of retro-reflection of beaded paint films on an area of approximately 1 x 1 inches. It was also proposed that the very low angle of incidence achieved with the Hunter instrument might be sacrificed for the sake of design simplicity.

The special reflectometer was constructed by adapting a Photovolt reflectance head to a small metal case which holds the head at an angle of 45° from the surface and directs the light beam to the target area at the bottom of the case through a

TABLE I

Test Results at One and Three Months Wear, Series II

aint No.	Stripe No	Film Thick. (mils)	One Months' Wear Integrity	One Months' Wear Hunter N. Vis.	Three-Months' Wear Integ.	Three-Months' Wear Hunter N.Vis.	Three-Months' Wear Spec 45° Refl.
15	101	10	6	9	3	4	10
	102	15	7	25	5	14	13
	103	20	8	51	6	23	22
29	104	10	9	27	7	19	10
	105	15	10	43	9	21	16
	106	20	10	53	10	19	20
36	107	10	7	20	6	13	13
	108	15	8	56	8	19	14
	109	20	7	62	7	14	15
37	110	10	6	19	5	9	13
	111	15	8	35	8	14	14
	112	20	10	43	9	25	21
38	113	10	6	10	4	13	12
	114	15	8	15	7	10	15
	115	20	9	23	7	13	17
are Concrete				2		3	3.6

TABLE II

Differences Between 10 and 20 Mil Thicknesses, Series II

aint No.	Stripe Nos.	One Months' Wear Integrity Diff.	One Months' Wear Hunter NV Diff.	Three Months' Wear Integrity Diff.	Three Months' Wear Hunter NV Diff.	Three Months' Wear Spec. NV Diff.
15	103-101	2	42	3	19	12
29	106-104	1	26	3	0	10
36	109-107	0	42	1	1	2
37	112-110	4	24	4	16	8
38	115-113	3	13	3	10	5
verage Difference		2	29	3	9	7

TABLE III

Differences Between 15 and 20 Mil Thicknesses, Series II

aint No.	Stripe Nos.	Integrity Diff.	Hunter NV Diff.	Integrity Diff.	Hunter NV Diff.	Spec. NV Diff.
15	103-102	1	26	1	9	9
29	106-105	0	10	1	2	4
36	109-108	-1	6	-1	-5	1
37	112-111	2	8	1	11	7
38	115-114	1	8	0	3	2
verage Difference		0.6	12	0.4	4	5

ath of about 6.5 inches. The operation of instrument is similar to that of the egular Photovolt Reflectometer except that reflectance standards from the Hunter nstrument are used instead of conventional reflectance standards. Figure 2 shows he instrument as used to measure reflectance of accelerated wear test panels, and igure 3 shows the arrangement for highway stripe tests.

Results obtained with the special reflectometer in comparison with the Hunter nstrument are presented in Table I. Figure 4 is a plot of corresponding points or the two instruments. The considerable scattering of data points is not particularly disturbing in view of the observable irregular wear on the traffic stripes t three months. The minimum value of approximately 10 obtained with the special eflectometer is one special characteristic of the instrument; the 45° bead orienation senses an appreciable component of diffuse reflectance in addition to bead etro-reflection. It has been observed that unbeaded white paints yield a reading f about 10 with this instrument, whereas the Hunter instrument yields readings of bout 2 for the same paint. On the other end of the scale the readings of the two nstruments converge toward the reflectance standard of 50. Two data points on igure 4 are shown with question marks; these points correspond to stripes No. 104 nd 106 in Table I. The data from the Hunter instrument would appear to be more uestionable in this case, since it appears to oppose a general trend of increasing eflectance with increasing film thickness.

It is unfortunate that the special reflectometer was not available at the time f the first months readings of Table I which were made at higher reflectance levels ith the Hunter instrument only. Nevertheless, either instrument is seen to be capable of discriminating useful differences in night visibility, and the special reflecance instrument is uniquely useful for the accelerated wear test.

B. Further development of Test Procedures

On October 8, 1963, testing was initiated on the first set of panels to e subjected to the full combined effects of UV irradiation and heating, water uenching and cooling, and drying. Data from these tests are summarized in Table IV nd plotted in Figure 5. This work was completed before the development of the pecial reflectometer and included no beaded formulations. The wheel loading of 0 pounds (55 pounds in prior work) was selected to extend the length of the test nd thus allow more time for cycling effects to contribute to the wearing process. he technique of performance comparisons at "normalized" 15 mil wet films was disussed in Progress Report No. 7 (July 26, 1963).

The data obtained from these tests, as compared with previous findings, demontrate very good internal consistency. There is agreement between the integrity ank ordering of Paints 15 and 16 and field results from Highway Series I. Neverheless, since the importance of bead retention and night visibility takes preceence over film integrity, it does not appear appropriate to continue with an exaustive study of unbeaded formulations. The apparent utility of the special eflectometer further supported a decision to concentrate subsequent work on beaded ormulations.

TABLE IV.

Initial Combined Effects Tests

anel No.	36		37		38	
ominal Wet Film	10 mils		15 mils		20 mils	
aint No.	Dry Film	Cycles to Failure(X100)	Dry Film	Cycles to Failure(X100)	Dry Film	Cycles to Failure(X100)
15	6.0	754	8.0	1073	13.3	1226
16	6.5	1222	9.7	1399	12.7	1669
29	6.3	754	11.0	964	11.7	1221
36	5.8	1177	7.5	1793	13.3	1880

OPERATING CONDITIONS

amps:

Distance - 10.5 in.
Cycle - on continuous

Wheel Load - 30 lbs.

Water:

Volume - Full
Cycle - On 1 min., off 59 min.

Of the several runs now completed with beaded formulations, a greater cattering of data is observed as compared with unbeaded studies. Further xperimentation with panel preparation and testing techniques should yield mprovements. However, a very pronounced effect of beading on paint durability has already been demonstrated. While this effect far exceeds similar ffects observed on Highway Series I, the shortcomings of the beading operaion on the highway tests must be taken into consideration in attempting any omparison. Panel No. 4C shown in Figure 6 illustrates the beading effect. ere each paint stripe is divided into two sections - the left section is eaded, the right section unbeaded. This panel has received 120,000 cycles of ear. Note that Paint #34 shows little wear on both sections, #39 and #11 show eavy wear unbeaded but only slight wear beaded, and #6 is worn through in both reas. These and other related observations further reinforce earlier concluions that beading plays a fundamental role in paint durability as well as ight visibility.

C. Current Work and Plans

The most recent runs of beaded and unbeaded paints tested adjacently n the wear tester appear to exaggerate the protective effects of beading considerably more than have prior field tests. Beaded paint presents a coarser urface to a running tire, and, since beads are large enough to receive compressive and shear stresses individually from tires, it seems reasonable to xpect that higher tire velocities might act to reduce the relative protection fforded the paint by the beads. Accordingly, the wheel speed on the accelerted wear tester has been doubled to more nearly simulate traffic conditions. his change will also be very helpful in reducing the testing time which has ecome excessive with beaded paints.

In further testing work efforts toward lab-field correlations will make ore use of Series II Highway tests, since the beading technique was much improved over the Series I tests.

It now appears that the limits of capability of the accelerated wear tester re being approached. As soon as adequate evaluations of the new operating conitions have been made, subsequent work will be directed exclusively toward paint ormulation improvement.

II. Formulation Studies

With the exception of some preliminary work on air drying urethanes and on ot melt plastics, no experimental formulation work was pursued during the past uarter. More concentrated effort is planned for the coming quarter. Subject o available test machine time, plans have been made to evaluate (1) air drying rethanes, (2) epoxy esters, and (3) hot melts.

Of higher priority, however, is a study of beading in current specification aint. In this connection it is interesting to examine the "first cost" economics f beading. If a gallon of specification paint costs \$1.20 and its volume solids ontent is 45 per cent, then the cost per gallon of solids is \$1.20/.45 = \$2.67.

f glass beads cost $0.10 per pound and weigh 22 pounds per solid gallon then hey cost $0.10 x 22 = $2.20 per gallon. Thus beads are significantly cheaper han paint solids. Aside from their contribution to night visibility and paint urability, potentially an optimum use of beads in a paint formulation could ven reduce the initial cost per mile of stripe. On the face of it, this looks oo good to be true, and in fact, it is probably not entirely true. The present ractice of beading could very nearly approach the maximum loading that is feasible; f so, no additional gain could be realized. Furthermore, the above calculations re premised on a "beads in" formulation which might not be fully equal in durabil- ty performance to the "beads on" type. The subject deserves careful study, and lans for this study are being made.

Respectfully submitted:

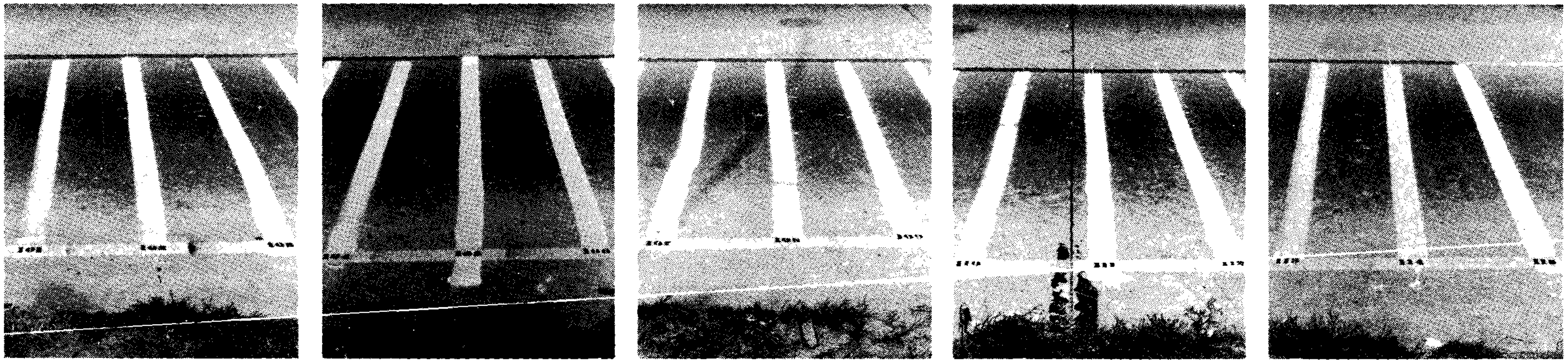
[redacted]

W. H. Burrows
Project Director

pproved:

[redacted]

rederick Bellinger, Chief
hemical Sciences and Materials Division



Stripes Photographed Immediately After Application

No. 15 Alkyd | No. 29 Alkyd, Min. | No. 36 Parlon-Alkyd | No. 37 Epoxy Polyamide | No. 38 Epoxy-Amine Adduct

Stripes Photographed At Three Months Wear

Figure 1. Effects of Three Months Wear on Series II Stripes.

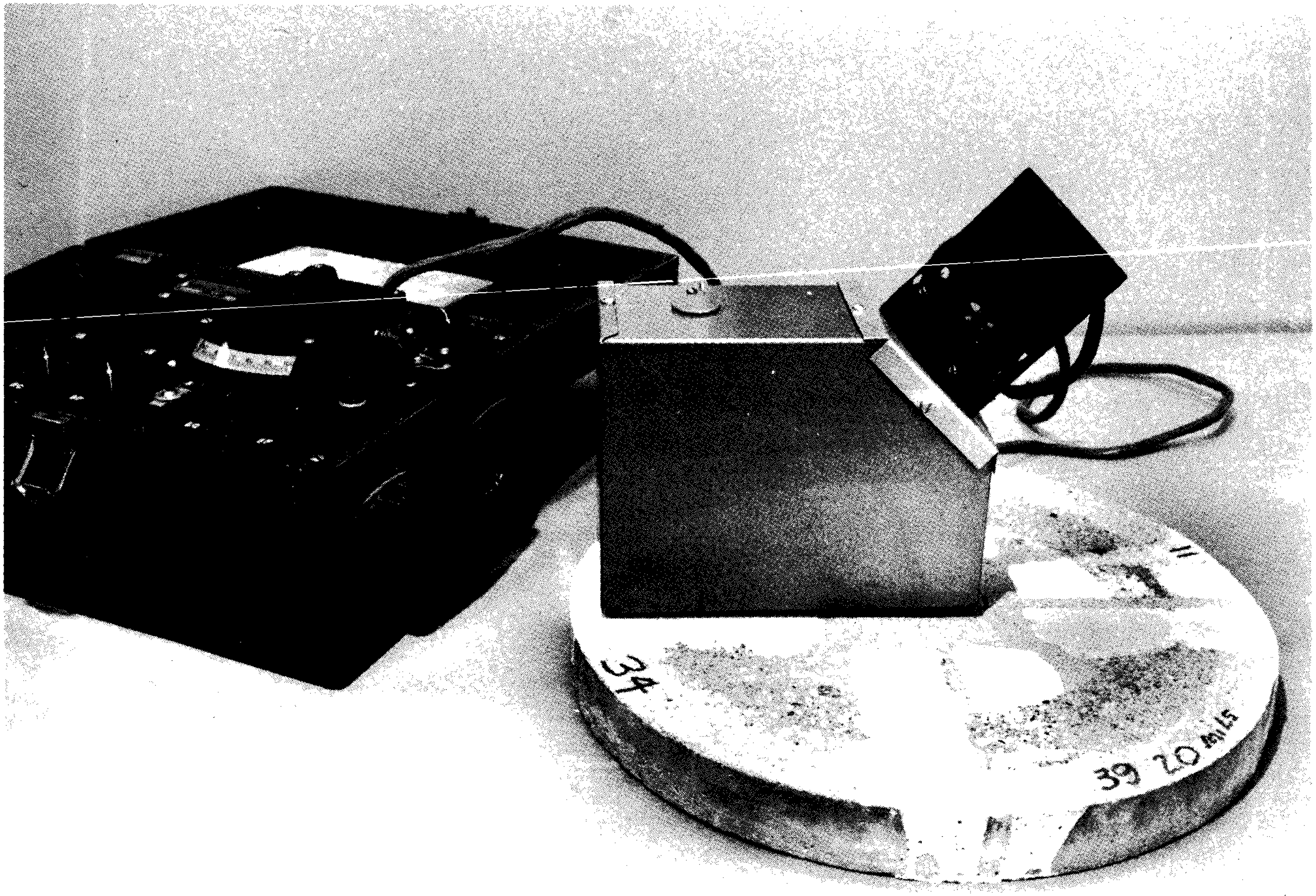


Figure 2. Special Reflectometer Measuring Accelerated Wear Test Panels.

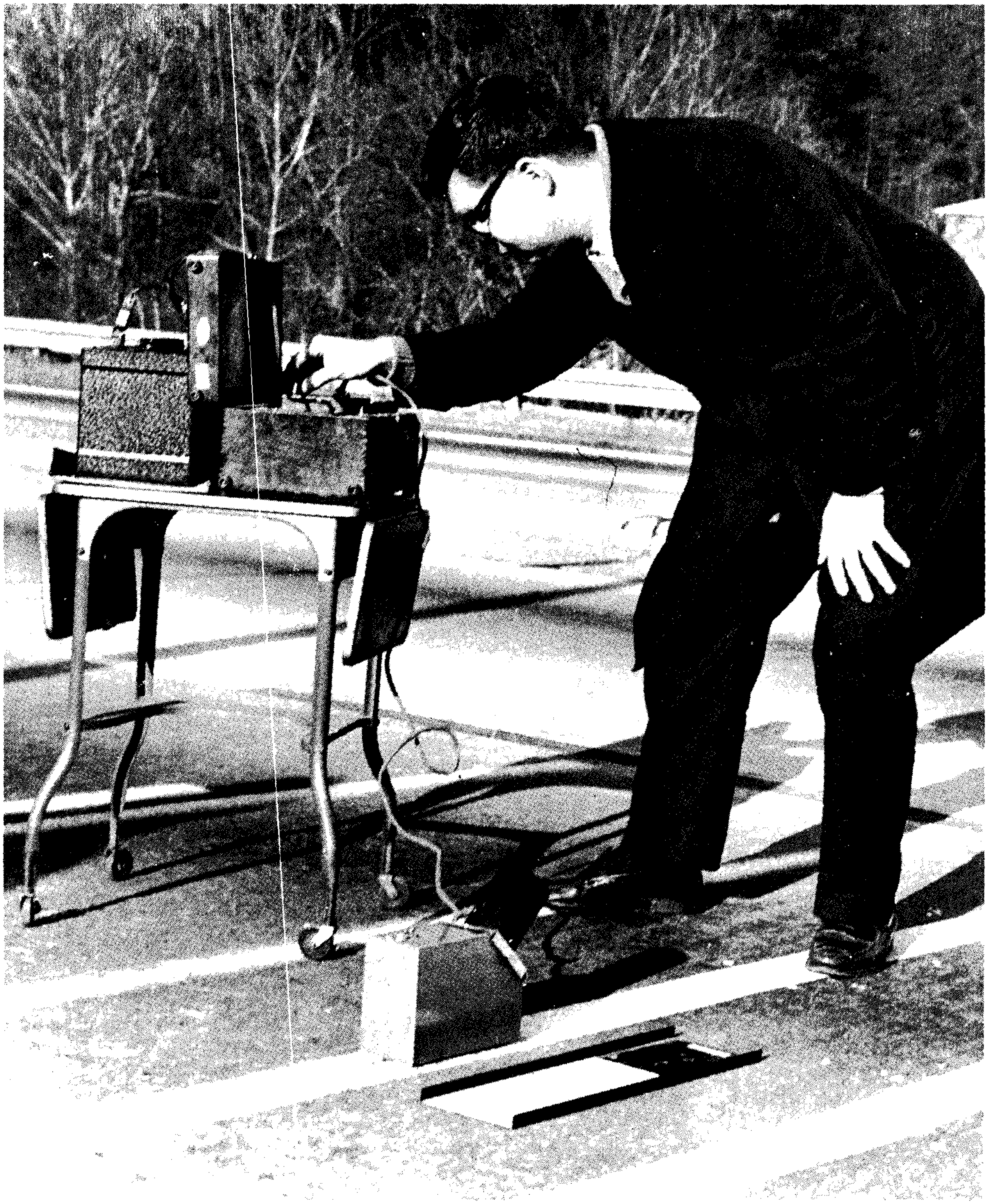


Figure 3. Special Reflectometer Measuring Highway Stripes.

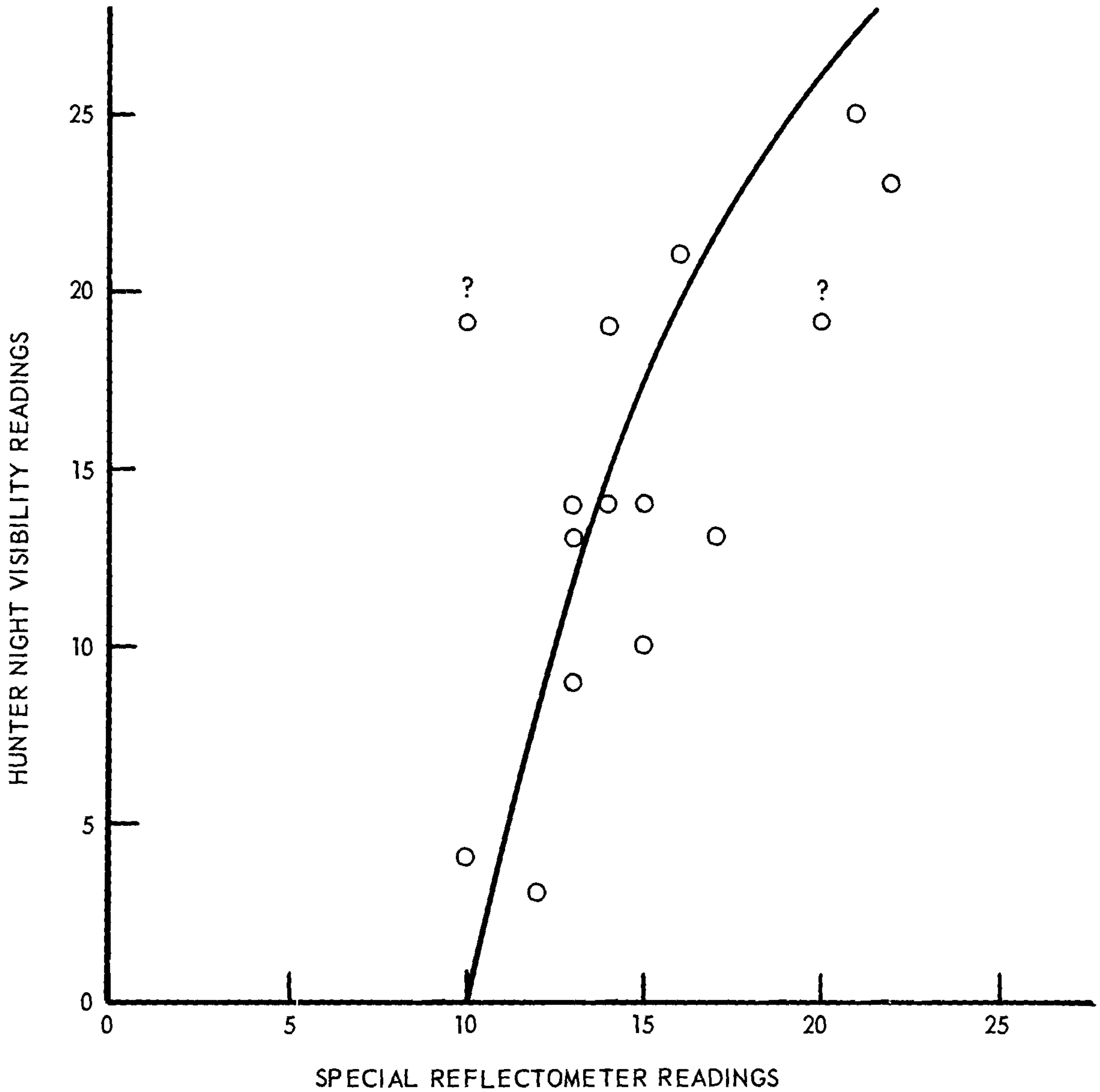


Figure 4. Corresponding Data Points for Hunter vs. Special Reflectometer.

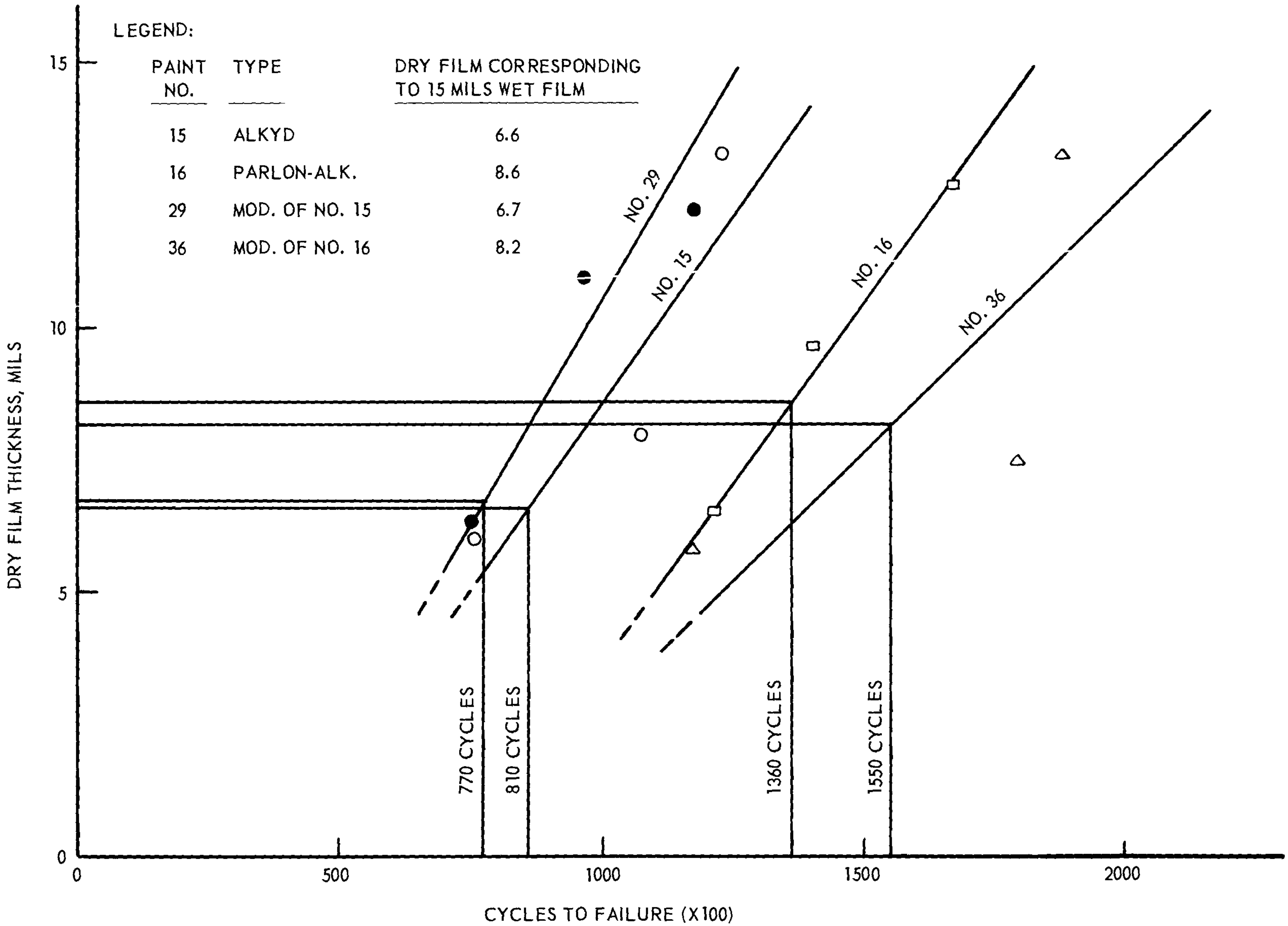


Figure 5. Relative Performance of "Normalized" Paint Films.

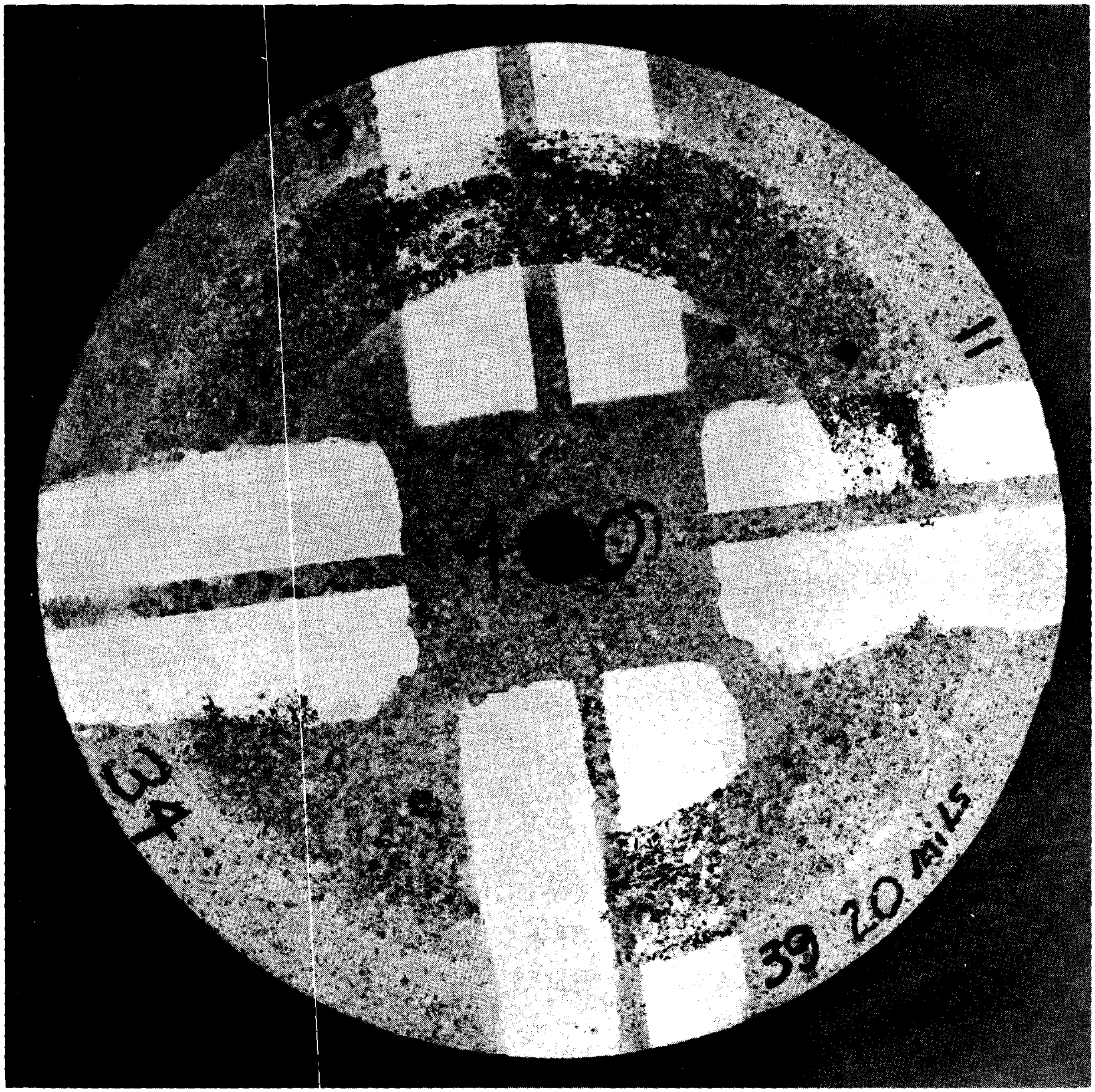


Figure 6. Beaded versus Unbeaded Performance.

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

June 8, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Quarterly Progress Report No. 10, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 January 1964 through March 31, 1964

Gentlemen:

During this period project activities have been conducted in the following areas:

1. Highway test stripes observations.
   A. Series I (applied 8/1/62).
   B. Series II (applied 9/3/63).
2. Correlation between highway and accelerated laboratory wear tests.
3. Infrared spectra of paint vehicles.
4. Modification of laboratory wear tester.
5. Formulation studies.

Additional details of the project work follow:

I. Highway Tests

A. Series I

Practically all of the test stripes were completely worn away at 18 months. Of the entire series on concrete, only Paint No. 15 (straight alkyd) and Paint No. 16 (chlorinated rubber alkyd) retained sufficient integrity to justify photographs. Photographs were taken of these stripes and are included in the Special Report on Series I Highway Test Applications.

B. Series II

For reference in the following discussion, the paints of this series are identified as follows:

Paint No.	Vehicle Type
15	Alkyd, linseed, 30% phthalic
29	Alkyd, minimum Ga. Specs. (similar to No. 15)
36	Chlorinated rubber modified alkyd, 50% PVC
37	Epoxy - polyamide
38	Epoxy - amine adduct

Integrity and night visibility of the cross stripes of the second series of paints applied on the highway drastically deteriorated over the winter months and at 6 months film integrity was in the range of 1 to 3 for the group. Performance profiles for integrity and night visibility are plotted in Figure 1. Note that surprisingly little difference in performance is shown among the group after six months exposure. It is believed that the extremely hard winter this year for this section of the country is the cause of the comparatively short life of the paints. The use of chains on cars on snowy and icy days, an unusual practice in this section, greatly decreased the life of the paint during winter months. At three months exposure, however, prior to the severe winter conditions, differences in the performance of these paints were well-developed. It is interesting to note that both integrity and night visibility decreased for all paints at a fairly uniform rate except for Paint No. 36 (alkyd-chlorinated rubber). In this case, the bead retention was poor, possibly because the paint dried or "skinned over" too fast to permit proper imbedding of the beads. The superior performance of thicker films is clearly demonstrated by Figure 2. Both night visibility and integrity show a positive response to increased film thickness for most of the paints.

II. Correlation Between Highway Tests, Series II, and Laboratory Wear Tests

For reference in the following discussion, the paints of this study are identified as follows:

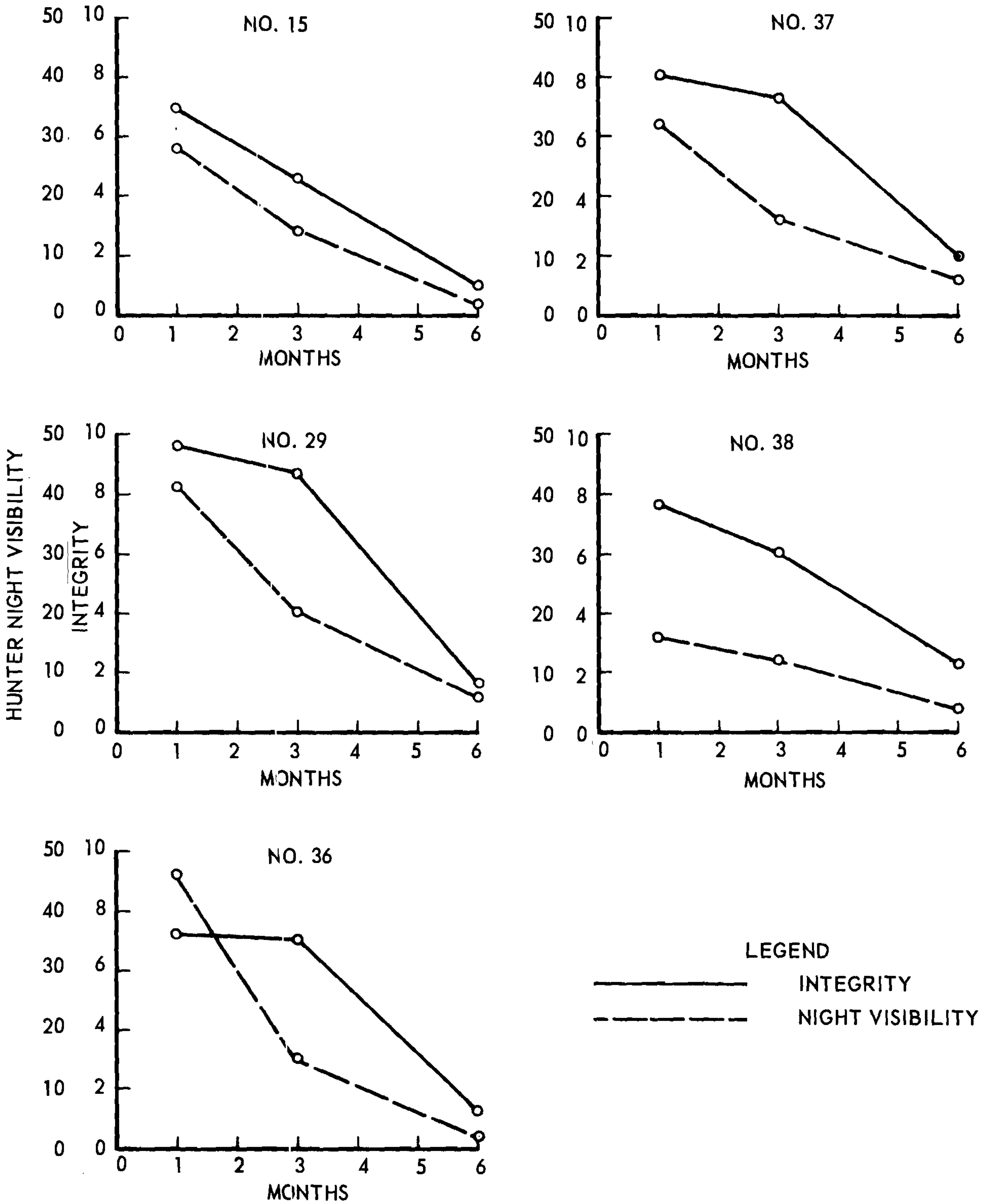

Figure 1. Performance Profiles, Highway Test Series II.

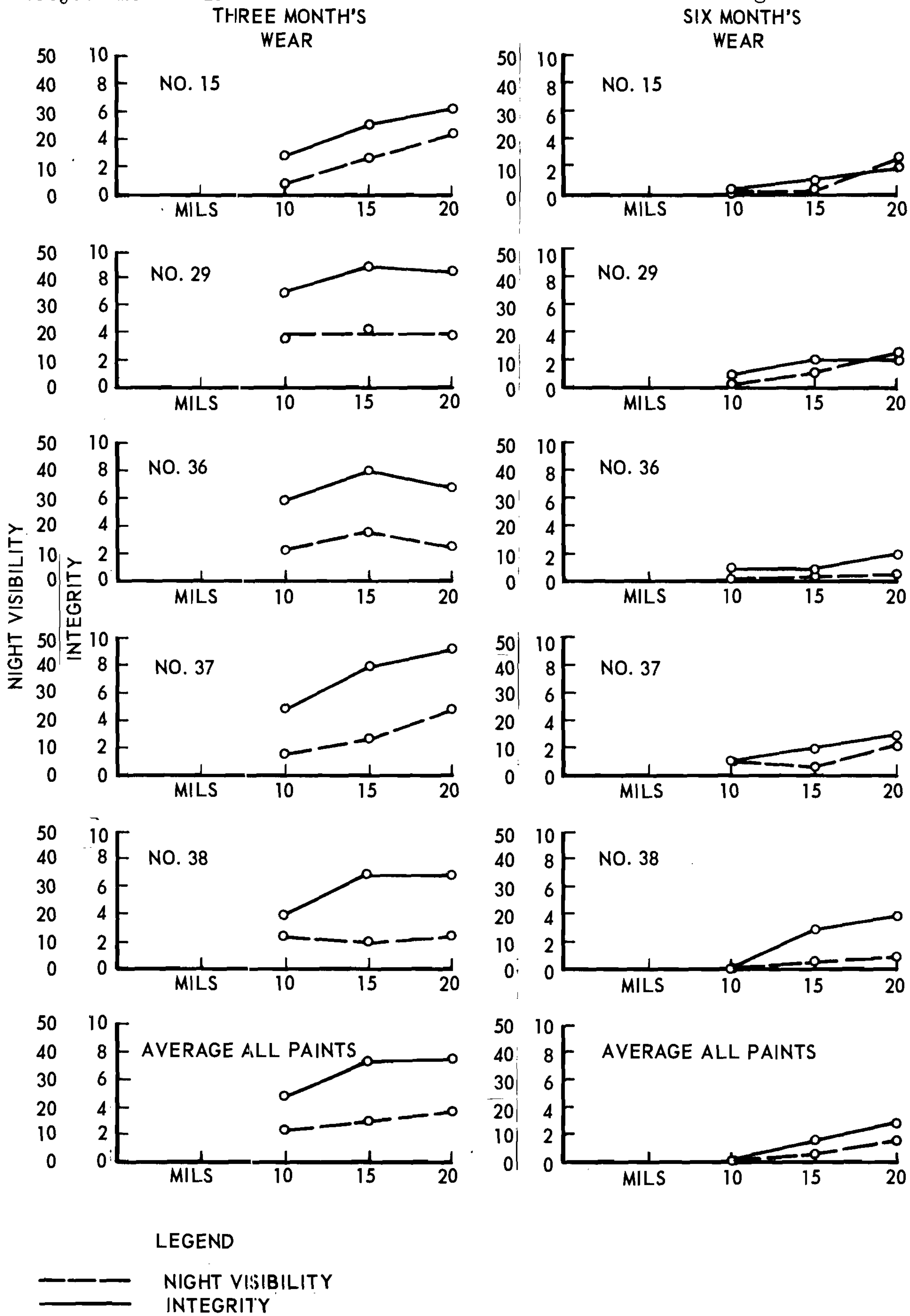

Figure 2. Integrity and Night Visibility versus Film Thickness, Highway Series II

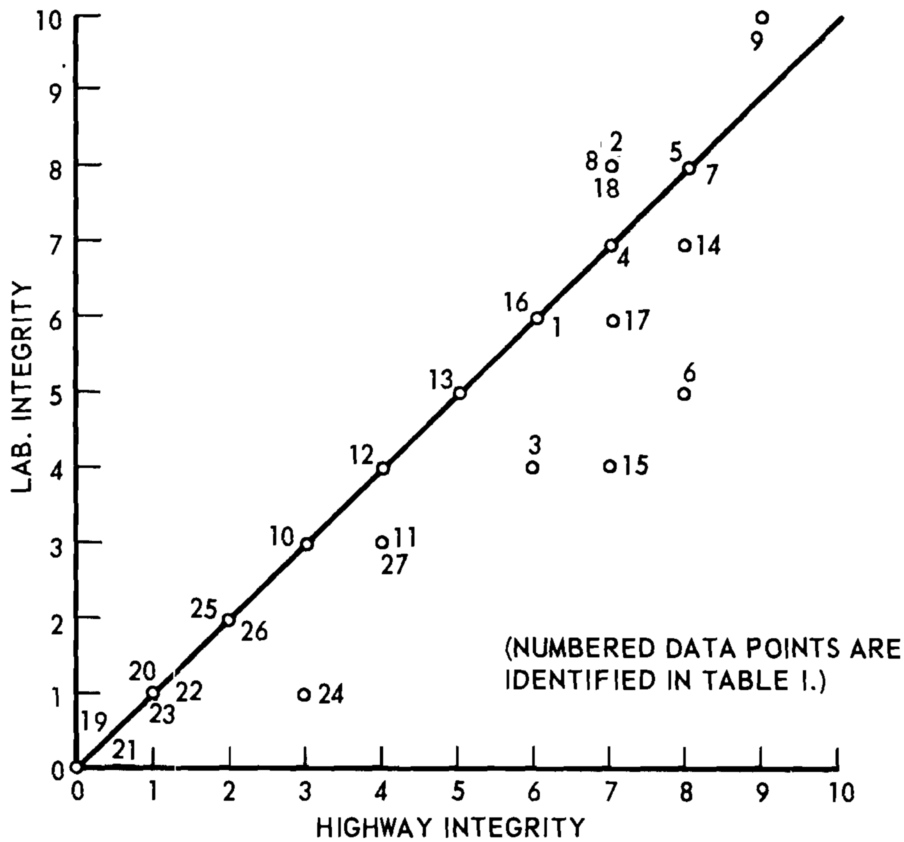

Figure 3. Integrity Correlation.

Paint No.	Vehicle Type
15	Alkyd, linseed, 30% phthalic
16*	Chlorinated rubber modified alkyd, 57% PVC
36*	Chlorinated rubber modified alkyd, 50% PVC
38	Epoxy-amine adduct

---

* Paints No. 16 and 36 were assumed identical for correlation purposes.

Figure 3 and Figure 4 show correlations between highway integrity and night visibility readings respectively versus corresponding laboratory wear data. The identification of the individual data points is given in Table I for Integrity and Table II for Night Visibility to assist in detailed interpretation of performance of specific paint systems.

The correlation method here presented was developed to eliminate as direct performance parameters both highway exposure time and laboratory wear cycles, since actual accumulation of wear is not linear with respect to either of these duration factors. As a premise, "true" correlation is assumed for the control paint (No. 15), and the correlations of test paints are reported relative to the control. In practice, sets of lab-field observations are matched where the control paint exhibits the same value on both. In cases where a perfect match does not occur, a linear interpolation of the lab values is utilized. In some cases, a proportional extrapolation has been utilized where the lab data does not extend to the very low values observed on the highway.

In correlating night visibility, it was necessary to convert Hunter readings to Special Reflectometer readings before proceeding with the correlations. Previous work (see Progress Report No. 9) has shown that the Special Reflectometer approaches a lower limit of 10 on white paints when the Hunter instrument approaches zero, and both instruments are calibrated against a standard having a value of 50. The instruments are so different geometrically that no single generalized correlation for all surfaces should be anticipated. For the present purpose where relative values of similar type surfaces are of primary interest, the straight line correlation shown in Figure 5 was utilized. Plans have now been made to make future measurements on the highway with the Special Reflectometer and thus eliminate the necessity for conversion.

Referring again to Figure 3 and Table I, a generally good correlation between laboratory and field values for integrity is observed. This is especially so since the plotted data points represent individual observations

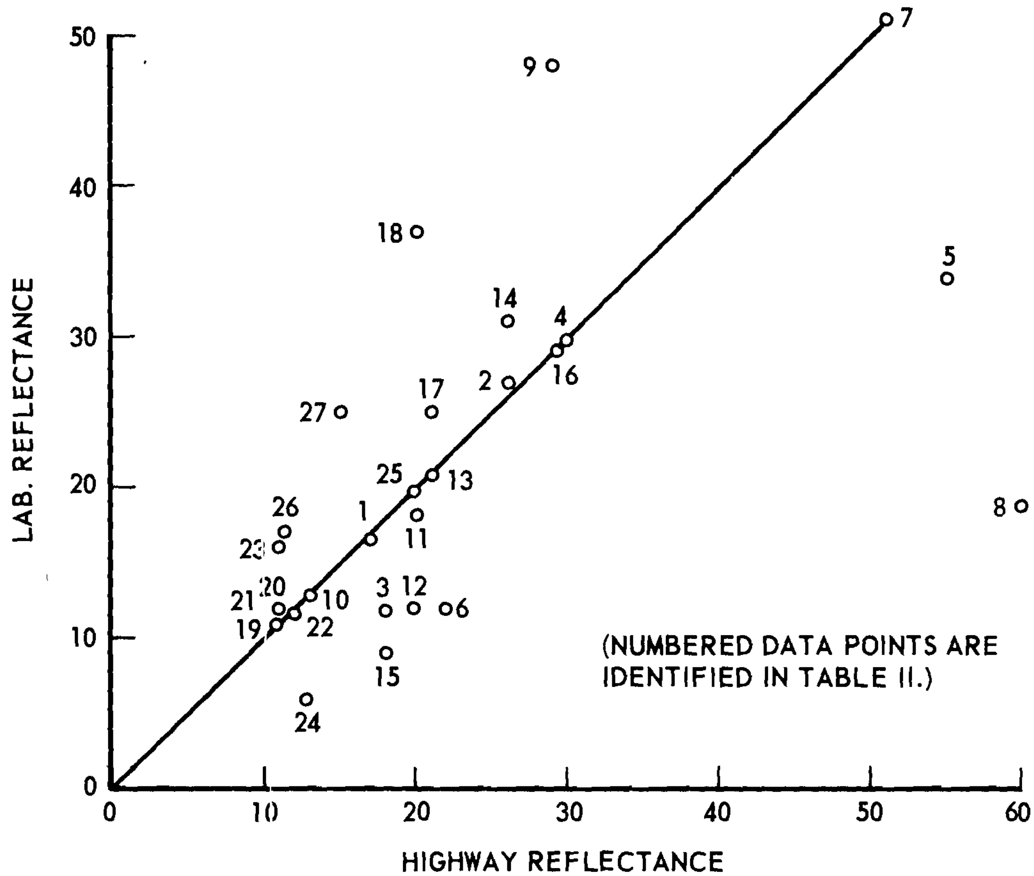

Figure 4. Night Visibility Correlation.

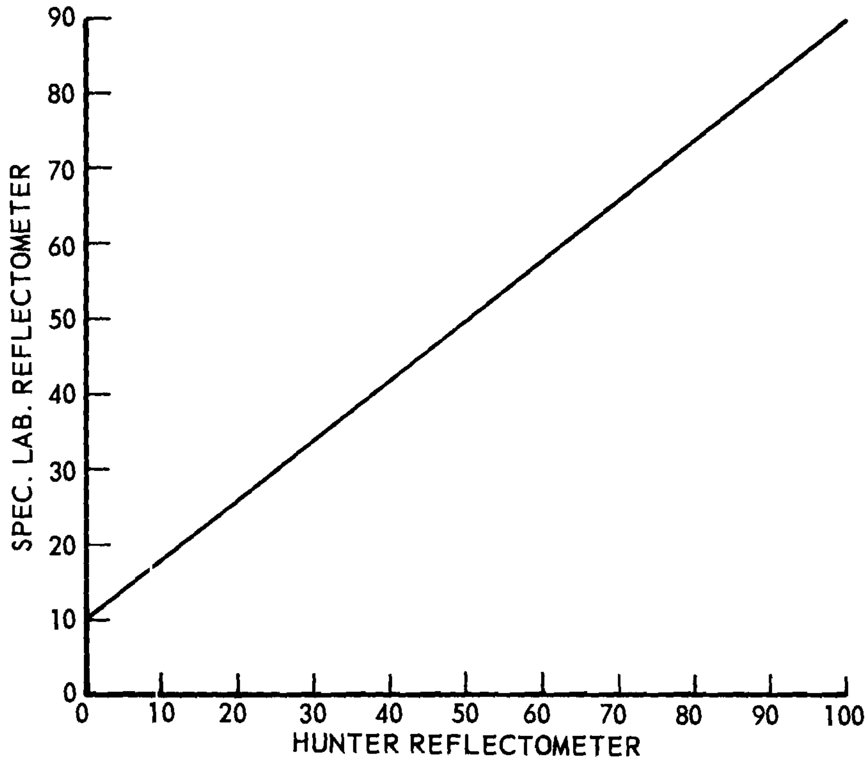

Figure 5. Correlation for Hunter and Special Reflectometer.

INTEGRITY CORRELATION DATA

Paint No.	Paint No.	Nominal Thickness (mils)	Highway Test Series II: Time (mos.)	Highway Test Series II: Integrity	Accelerated Laboratory Test, Low Value: Hundreds of Cycles	Accelerated Laboratory Test, Low Value: Integrity	Accelerated Laboratory Test, High Value: Hundreds of Cycles	Accelerated Laboratory Test, High Value: Integrity	Adjusted Accel. Test Value
1	15	10	1	6	972	6	-	-	6
2	16.36	10	1	7	972	8	-	-	8
3	38	10	1	6	972	4	-	-	4
4	15	15	1	7	1127	7	-	-	7
5	16.36	15	1	8	1127	8	-	-	8
6	38	15	1	8	1127	5	-	-	5
7	15	20	1	8	918	8	-	-	8
8	16.36	20	1	7	918	8	-	-	8
9	38	20	1	9	918	10	-	-	10
10	15	10	3	3	-	-	1200	5	3
11	16.36	10	3	6	-	-	1200	7	4
12	38	10	3	4	-	-	1200	4	2
13	15	15	3	5	1482	5	-	-	5
14	16.36	15	3	8	1482	7	-	-	7
15	38	15	3	7	1482	4	-	-	4
16	15	20	3	6	2383	5	1762	7	6
17	16.36	20	3	7	2383	5	1762	7	6
18	38	20	3	7	2383	7	1762	9	8
19	15	10	6	0	1200	5			0
20	16.36	10	6	1	1200	7			1
21	38	10	6	0	1200	4			0
22	15	15	6	1	2251	4			1
23	16.36	15	6	1	2251	5			1
24	38	15	6	3	2251	4			1
25	16.36	20	6	2	2383	5			2
26	16.36	20	6	2	2383	5			2
27	38	20	6	4	2383	7			3

NIGHT VISIBILITY CORRELATION DATA

			Highway Test Series II			Accelerated Laboratory Test				Adjusted Accelerated Test Values
						Low Value		High Value		
Paint No.	Paint No.	Nominal Thickness (mils)	Time (mos.)	Hunter N.V.	Special N.V. Converted from Hunter	Hundreds of Cycles	N.Vis.	Hundreds of Cycles	N.Vis.	
1	15	10	1	9	17	972	15	819	20	17
2	16.36	10	1	20	26	972	24	819	31	27
3	38	10	1	10	18	972	12	819	17	14
4	15	15	1	25	30	1127	23	918	32	30
5	16.36	15	1	56	55	1127	32	918	35	34
6	38	15	1	15	22	1127	10	918	13	12
7	15	20	1	51	51	0	51			51
8	16.36	20	1	62	60	0	19			19
9	38	20	1	23	29	0	48			48
10	15	10	3	4	13	1200	13			13
11	16.36	10	3	13	20	1200	18			18
12	38	10	3	13	20	1200	12			12
13	15	15	3	14	21	1263	17	1127	23	21
14	16.36	15	3	19	26	1263	28	1127	32	31
15	38	15	3	10	18	1263	8	1127	10	9
16	15	20	3	23	29	918	29			29
17	16.36	20	3	14	21	918	25			25
18	38	20	3	13	20	918	37			37
19	15	10	6	1	11	1200	13	972	15	11
20	16.36	10	6	1	11	1200	18	972	24	12
21	38	10	6	1	11	1200	12	972	12	12
22	15	15	6	2	12	2251	16			12
23	16.36	15	6	2	12	2251	21			16
24	38	15	6	4	13	2251	8			6
25	15	20	6	13	20	1762	23			20
26	16.36	20	6	2	12	1762	19			17
27	38	20	6	6	15	1762	29			25

rather than averages. The greater incidence of points below the diagonal line indicates that the laboratory test tends to be relatively more severe in its evaluation of experimental paints. It should not be too surprising that the night visibility correlations of Figure 4 and Table II exhibit data points that are considerably more scattered. The sources of experimental error are greater for this parameter, especially because of the instrument conversion required, but qualitatively the correlation is still good.

At this time no endeavor to develop a more quantitative treatment of these correlations will be made; rather, comments and critique on the methods presented are being solicited with a view toward gaining possible improvements in the approach to the correlation problem.

III. Infrared Spectra of Paint Vehicles

Infrared spectra have been run on all paint vehicles of current interest in the test program. The spectra are included as a part of the "Special Report on Highway Cross-Stripe Tests of Traffic Paints, Series I."

It is of special interest to note that most of the special vehicles studied exhibit distinct characterizing infrared spectra. Unfortunately, chlorinated rubber is so similar to alkyd in its spectrum that it appears virtually impossible to distinguish combinations of these materials.

IV. Laboratory Wear Tester Modification

A shock absorber was attached to the driving wheel carriage of the laboratory wear tester. This resulted in much smoother running of the machine and eliminated the development of flat spots on the rubber tire. An additional change was planned to provide a floating bearing to replace one of the fixed bearings supporting the driving wheel carriage. This modification will eliminate any thrust and resultant dragging action of wheel which could be caused by slight misalignments that could otherwise occur unobserved.

V. Formulation Studies

A. Epoxy Esters

The necessary equipment for cooking and checking the progress of the reaction for preparing epoxy esters has been set up.

B. "Beads In" Paints

"Beads in" paints have been prepared and are being tested, using different PVC levels of the alkyd vehicle paint and various bead concentrations. This series of tests is almost completed.

C. Hot Melt Composition

Samples of hot melt composition used by the City of Atlanta for their traffic stripes were obtained and a method for application of this material on concrete discs was explored. No further work was undertaken pending action on a proposal prepared on this subject.

D. Wet Visibility Concept

A number of special small shapes were prepared and coated with glass beads. Bead application was not fully satisfactory, and this work continues on an occasional basis.

Respectfully submitted:

[redacted]

W. H. Burrows,
Project Director

Approved:

[redacted]

F. Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

August 17, 1964

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Quarterly Progress Report No. 11, Project No. HPS-1(60), Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 April through 30 June 1964.

Gentlemen:

Project activities during the period covered by this report have included:

I. Accelerated Wear Test Development

   A. Self Alignment Modification
   B. New Abrasion Wheel

II. Formulation Work

   A. "Beads-In" Study
   B. Epoxy Ester Synthesis

III. Other Activities

   A. Night Visibility Media
   B. Patent Reviews

Further details on these activities are given below:

Self-Alignment Modification of Wear Tester:

During April it became evident that various necessary adjustments of the wheel carriage had caused changes in alignment of the drive wheel. Except for observation of changes in the wear pattern over a long period, there was no way to accurately assess "trueness" of wheel alignment with adequate precision. To correct this shortcoming, a "floating" bearing suspension was designed and installed on the idler shaft to provide self-alignment of the drive wheel to a "true" position. This completely eliminated the possibility of development of lateral thrusts and resultant excessive drag on the drive wheel. Subsequent experience appears to have confirmed the value of this modification for maintaining uniform wearing conditions.

New Abrasion Wheel:

Accelerated wear testing with beaded paints was observed to require substantially longer tests than in previous work and tread wear became excessive. In some cases one test completely wore out the special abrasive rubber ring. Furthermore, there were indications that rings may vary in their condition of cure. To correct these shortcomings, a new drive wheel assembly, designed to accomodate tires molded of commercial tread stock, was installed and operated. However, the tire tread, even when cured well beyond conventional levels, developed a tacky surface and transferred black gum to the test disc when operated on the accelerated wear tester. When a small amount of fine sand was distributed to the disc, the tread rubber rapidly assumed a conventional appearance and the tackiness disappeared. It was apparent, therefore, that "road dust" must be supplied to the disc if realistic operation was to be attained utilizing a tread stock abrading wheel.

Much mechanical experimentation was required to develop a suitable metering device for the fine sand abrasive. The final design consists of a transparent cylindrical sand reservoir which supplies sand to a small glass tube having a constriction, thence to a rubber tubular section which functions as a pinch valve to interrupt sand delivery, and finally through a copper delivery tube to the disc surface. The pinch valving operation is actuated by a solenoid and controlled by a timing device.

Satisfactory precision and reliability of this device has been established and experimentation is now in progress to determine the most appropriate timing cycle (controlling the quantity of abrasive consumed) and tire loading to attain desired wear rates.

It has been observed in the course of the foregoing experimentation that the new tread stock wheels are wearing at an extremely slow rate as compared with the special eraser stock treads previously used. The problem of excessive tread wear appears to have been resolved.

"Beads-in" Study:

This formulation study was run on the accelerated wear tester as a designed experiment with a standard alkyd traffic paint to determine the effects of pigment volume concentration, bead volume concentration and film thickness on film integrity and night visibility. It was found that when beads are incorporated in paint prior to application, a large increase in paint durability is observed on the accelerated wear tester. The abrasive rubber rings were worn away rapidly by the "beads-in" paints, and changes in the character of the rubber surface were observed as the tests progressed. Despite this difficulty, the tests indicated the best levels of pigment volume concentration and beading to achieve maximum durability. The tests also demonstrated that "beads-in" paints require a considerable period of wear and weathering before any appreciable night visibility is attained; but after this weathering period, night visibility retention is superior to "beads-on" paints. For practical use it appeared obvious that a "bead-on" technique is required even with paints containing a large volume of pre-mixed beads if adequate initial levels of night visibility are to be obtained. Accordingly, further laboratory and field experiments on beading technique were planned to evaluate such practical systems.

Epoxy Ester Synthesis:

The good performance exhibited by selected alkyd varnishes as traffic paint vehicles has suggested that this type of vehicle is a most appropriate starting point for developing further improvements in performance. If toughness, water resistance, and adhesion could be enhanced without losing other desirable properties, the objective should be realized. Epoxy esters appeared to be capable of meeting these requirements. In effect, the glycerol phthalate backbone of the alkyd was to be replaced with epoxy resin while leaving the fatty acid portions of the molecule relatively unchanged.

An epoxy ester of this type has been synthesized in the laboratory. Traffic paint prepared from this vehicle was observed to have similar characteristics to the alkyd paint, but with a slight increase in film hardness. Preliminary tests on the accelerated wear tester indicate a probable superiority of the new paint as compared with the alkyd type.

Other Activities:

Means of enhancing night visibility properties of traffic paints under wet weather conditions is a subject of continuing interest. Preparation work on small retroreflective shapes has been pursued as a minor activity.

The "beads-in" patent art was reviewed during this period, but a report of findings was deferred pending consultations with patent counsel.

Future Plans:

Major emphasis will continue to be directed toward developing the full capabilities of the accelerated wear tester for predicting traffic paint performance.

Most of the future experimental work will be designed to permit rigorous statistical analysis. Further attention will also be directed toward correction of some recognized shortcomings in test panel preparation. In particular, means will be studied to permit controlled uniform "bead-on" application to test panels.

A third series of highway tests will be scheduled for application during the next quarter to provide further correlations data and to evaluate several of the latest formulation and application concepts.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

October 9, 1964

MAY 1969
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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 11,
Quarterly Progress Report No. 12
Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 September 1964 through 31 September 1964.

Gentlemen:

Project activities for July, August, and September were conducted in the following areas:

1. Accelerated Wear Testing
2. Highway Tests
3. Night Visibility Media
4. Other Activities

A discussion of these activities follows:

I. Accelerated Wear Testing

A. Test Machine Studies

Quarterly Progress Report No. 11 reported the installation of a sand metering device in an effort to eliminate transference of heavy black marks from tread stock tires to paints on the concrete test disc. After a period of operation with this sanding device it became evident that black marks would still hamper the tests. Experimentation with another type of black tread stock yielded less tread wear, but insufficient reduction in the black marking. A special white tread stock was investigated. This material produced no marks, but its wear was non-uniform and rapid. This test situation was considered unsatisfactory.

Up to this time the tester had been operated on a cycle of 59 minutes dry, 1 minute wetted. It was suspected that the marking from black treads would not occur on a wetted surface. This was confirmed by experimentation on a continuously wetted disc. This experiment also reconfirmed the occurrence

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of greatly increased wear rates on wet surfaces. Further, it was found that a cycle consisting of 45 minutes of wetting followed by a 15 minute drying period (paint fully dried) did not exhibit the tire marking effect.

It will be seen that these results forced a reappraisal of the testing rationale. Other investigators have found that laboratory wet abrasion tests provide better correlation with highway results than any other uniform test condition. Unquestionably, however, wetting-drying-heating-cooling changes affect adhesion of paint films to concrete, and cannot be ignored in a comprehensive accelerated test. If changes during long continuous dry periods on a highway can be regarded as relatively slight, then why attempt to simulate these periods in an accelerated test? Rather, may we not seek to attain in the laboratory test a balance between total time of wet abrasion and wetting-drying-heating-cooling cycles which most nearly simulates the balance of these factors as they occur in the field?

With these considerations in mind, the wetting-drying-heating-cooling was altered to a 30 minute environmental cycle of 20 minutes wetting-cooling and 10 minutes drying-heating in order to gain further acceleration of this environmental factor. Even so, when the machine was operated with minimum wheel loading, abrasion effects were so rapid that only about 5 environmental cycles could be completed before the paint was worn through by abrasion.

It was believed that the machine must have the capability to fully control the relative intensity of these paint deterioration factors. Since varying wheel loadings could not accomplish this objective, it appeared necessary to modify the machine to vary wheel velocity. A suitable variable speed drive for this purpose will be installed as soon as possible.

It is proposed that future work with the wear tester shall encompass conditions and effects ranging as follows:

1. Continuous wet abrasion, high speed - abrasion factor only.
2. Environmental cycling, several intermediate speeds - combined factors.
3. Environmental cycling, lowest speed - environmental factor dominant.

By establishing the responses of standard paint systems to this range of conditions, the capabilities of the tester for correlation with various field conditions will be defined.

B. Test Panel Preparation on Concrete Discs

Significant improvements in uniformity of paint application to test discs have been achieved by utilizing single metal templates cut to the complete disc application pattern. The templates, of selected thicknesses, effectively control paint drawdown thicknesses and spacing on the discs.

As reported in Monthly Progress Report No. 10 (9/9/64), a simple bead distributor has been developed which applies beads to the small test paint sections on the disc to quantitatively simulate field applications. The distributor has been calibrated so that any desired level of beading concentration can be attained. A number of paint specimens on discs have been prepared at a loading of 6 lbs of beads per gallon. Excellent bead distribution was observed on these panels.

II. Highway Tests

On September 2, 1964 application of a cross-stripe test series was initiated on the Atlanta Northeast Expressway. A mechanical failure of the application equipment forced abandonment of the application at that time. It was also disclosed that the spray equipment would not handle the experimental pre-mixed beaded paints with adequate reliability (stopages). These paints are being reformulated with a much finer gradation of beads and somewhat lower beading concentration as dictated by equipment limitations. This application is to be rescheduled as soon as feasible.

III. Night Visibility Media

Beading was applied to the previously prepared special small shapes in a quantity sufficient to permit a bench scale evaluation of performance. The highway viewing geometry is being approximated at about 1/10 scale to permit direct comparisons of regular beaded paint with media-treated paint under wet and dry conditions. It is not anticipated that the crudely prepared media will approach its full capabilities, but the relative wet and dry reflective intensities should provide an indication of the practical potential of the concept. The setup for these tests is essentially complete except for final precise illumination and viewing (photographic) positionings.

IV. Other Activities

A review of "beads-in" patent art was completed. Further revisions have been made in technical reports being drafted. Increased attention is being directed to statistical design and analysis of experiments.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

F. Bellinger, Chief
Chemical Sciences and Materials Division

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ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

April 5, 1965

State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

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Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Quarterly Progress Report No. 14
Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 January 1965 through 31 March 1965

Gentlemen:

Project activities during the current quarter have included the following topics: (1) accelerated wear testing, (2) highway tests, and (3) other activities. A discussion of each of these topics follows:

I. Accelerated Wear Testing

In the previous Quarterly Report #13, three sets of operating conditions for the tester were tabulated, and the results obtained with each were described. In a continuing effort to attain better correlation with the chipping type of failures observed in the field, a fourth operating condition has been explored, and it appears to provide an improved approach to adhesion-chipping evaluation. The four operating conditions are summarized below:

	Operating Conditions			
	I	II	III	IV
Wheel Speed, RPM	100	40	10	100
Wheel Load, lbs.	40	40	40	5
Water Cycle:				
On, min.	Continuous	20	5	5
Off, min.		10	25	25
Abrasive Feed, g/hr.	17	17	none	none
Substrate Treatment	none	none	none	impregnated

The character of the results are reviewed briefly as follows:

Condition I. Very rapid erosive failure, bead retention cannot be observed.

<u>Condition II</u>. Moderate rate of erosive failure, bead retention can be observed as a function of time.
<u>Condition III</u>. Extremely slow (200 hrs.) failure by cracking, spalling, and chipping. Rubber wheel becomes tacky.
<u>Condition IV</u>. Initial film failures by cracking, spalling, and chipping develop in 10 to 20 hours. Among a series of impregnants evaluated including oil, low molecular weight polyethylene, paraffin wax and microcrystalline wax, the latter appeared to provide the best combination of surface uniformity and reduction of adhesion without unduly affecting the drying characteristics of the paints. This treatment has been tentatively adopted as standard for this test.

The attainment of accelerated failure by Condition IV required a large increase in wheel speed, a reduction in wheel loading, and an impregnation of the concrete substrate to reduce adhesion. The high speed with a low loading of the drive wheel produces a random bouncing of the wheel which increases the impact loadings applied to the paint film. A pronounced tendency for spalling-type film failure suggests that shear impact may tend to predominate. Surface impregnation was seen to accelerate the rate of failure and enhance the chipping effect so that an approximation of recently observed modes of failure on the highway has been realized. At the same time, the virtual absence of spalling failure on highway observations suggests that shear impact is not a significant factor in paint failure in service. Since only a few panels have been run under Condition IV, it would be premature to attempt to discuss correlation in detail at this time. In addition to the spalling, we have noted that film failure tends to be erratic, and failures which initiate within 20 hrs. frequently do not progressively worsen for very extended periods thereafter. This is in distinct contrast to a fairly uniform progression of failure observed on the highway, and suggests the possibility that our impact loadings may be below a "threshold" value that may be required to develop uniform failure progression. Some increase in impact loading may be feasible; however, this will tend to aggravate spalling. It may be more productive to attempt to further reduce adhesion by impregnation pretreatment of the test discs.

That the impregnation of the substrate can render the system quite unrealistic is fully recognized. This expedient is justified on the basis that the testing machine is inherently incapable of dynamic similitude with the highway, although it may be capable of indicating the relative adhesion of paints if substrate adherence is uniformly reduced. This relative adhesion is now believed to be the predominant factor controlling highway service performance.

The foregoing considerations have defined rather narrow limits for further exploratory studies with the accelerated wear tester, and the necessary experimental work is being expedited to conclude this activity.

II. Highway Tests, Series III

This series of highway tests placed on exposure on November 12, 1964, was observed for integrity and night visibility at 0, 3, 9, and 17 weeks weathering, and photographs of the stripes were made at each observation. An additional observation (excluding night visibility) and photographs were made at 10 weeks immediately following an ice storm. The complete data for this study are given in Tables I, II, III, IV, and V. Integrity ratings are based on the photographic standards for erosion or chipping (ASTM D821-47 and D913-51) where 10 is perfect and 0 is poorest condition conceivable. Night visibility determinations with the Hunter Reflectometer and the Special Reflectometer are based on ASTM D1011-52 procedures. It will be recalled that the Special Reflectometer employs different illumination angles from the Hunter instrument, and thus correlation between the two instruments can only be approximated.

A more detailed reporting of all series of highway tests is being accumulated into two Special Technical Reports; therefore, the present discussion will be confined to the principal findings of Series III.

Effect of Concrete Surface Condition. The control paints have displayed a rate of wear definitely greater than in Series I or II, and chipping has become the overwhelmingly predominant mode of failure. These differences are attributed primarily to differences in the texture, degree of contamination, and wear condition of the concrete roadway at the several test sites. In our judgment, the effects of all other experimental and environmental factors could not possibly account for the observed differences. Under these circumstances, for good quality paints, erosion resistance becomes irrelevant and performance is primarily dependent upon adhesion.

Relative Paint Performance. The test results for the various "bead on" paint formulations have been summarized in two plots. Figure 1 shows integrity and night visibility of each paint as a function of the service period. Perhaps the most distinguishing feature of this study is the general similarity of results for the several paints studied. Paint #86 (Pliolite VT) was slightly poorer in integrity and definitely poorer in bead retention than the other paints. A tendency to darken or stain was also noted in this material. Excepting some tendency for slow dry (slight traffic smears) in Paint #88 (epoxy ester), the performances of Paints #84, 88, and 90 were very similar. Particular attention is directed to a double coat application of Paint #90 (alkyd). A suggestion to include this special study had been received from B.P.R. The enhanced durability of this two coat (15 mils + beads each coat) application was clearly outstanding. A photograph of the double coat stripe for Paint #90 at 17 weeks' service is shown in Figure 2.

Beading, Bead On, Bead In. The effect of "bead on" beading in enhancing paint integrity was clearly demonstrated again for all paints. The enhancement was less pronounced for the "bead in" paints. The "bead in" paints did not display significantly superior integrity as compared with the plain paints; however, they did maintain night visibility at uniformly higher levels.

Film Thickness. The data clearly shows enhanced integrity and night visibility with increasing film thickness. The integrity effect is less pronounced than for previous series, because the chipping mode of failure is somewhat less sensitive to film thickness than is erosive failure. Among the "bead in" paints at 20 and 30 mils, the thickness effect was negligible.

TABLE I

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
INITIAL OBSERVATIONS

aded-Unbeaded	Reg. Alkyd B	Reg. Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
					Integrity				
int No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	10	10	10	10	10	10	10	10	
15 mils	10	10	10	10	10	10	10	10	10
20 mils	10	10	10	10	10	10	10	10	
int No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	10	10	10	10	10	10	10	10	
30 mils	10	10	10	10	10	10	10	10	
					Hunter Night Visibility[o]				
int No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	45(32)	1.03(8)	18(20)	0.8(7)	14.0(40)	1.0(10)	40(7)	30(7)	
15 mils	25(24)	1.0(5)	20(20)	1.0(7)	4.0(26)	1.0(10)	30(52)	1.6(10)	50
20 mils	20(57)	0.8(5)	8(34)	5.0(10)	20.0(23)	2.0(8)	10(59)	1.4(9)	
int No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	20(34)	25(10)	25(33)	2.0(8)	25(17)	2.3(12)	11(64)	0.4(15)	
30 mils	6(50)	3.5(11)	30(43)	2.5(10)	40(38)	1.2(12)	0.8(70)	1.0(13)	
					Special Reflectance				
int No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	34	16	26	15	43	18	15	15	
15 mils	30	14	26	15	32	18	52	18	29
20 mils	56	14	38	18	28	16	60	17	
int No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	32	18	35	16	24	20	62	22	
30 mils	50	19	45	18	41	20	67	21	

The Hunter instrument was observed to be functioning erratically during these measurements, therefore approximate equivalents based on the Special Reflectance measurements were computed and are shown in parentheses.

TABLE II

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
3 WEEKS OBSERVATIONS

Beaded-Unbeaded	Reg. Alkyd B	Reg. Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
Integrity									
Paint No. 0% BVC	90	90	88	88	84	84	86	86	90
10 mils	7[x]	4[x]	8[x]	7[x]	7[x]	6[x]	6[xx]	7[xx]	
15 mils	9[x]	4[x]	9[x]	6[x]	9[x]	8[x]	7[xx]	9[xx]	8[x]
20 mils	8[x]	5[x]	9[x]	7[x]	10[x]	8[x]	9[xx]	9[xx]	
Paint No. 45% BVC	91	91	89	89	85	85	87	87	
20 mils	8[x]	7[x]	9[x]	8[x]	7[x]	8[x]	7[xx]	8[xx]	
30 mils	9[x]	7[x]	7[xx]	7[xx]	10[x]	9[x]	8[xx]	8[xx]	
Hunter Night Visibility									
Paint No. 0% BVC	90	90	88	88	84	84	86	86	90
10 mils	26	3	40	4	13	3	20	3	
15 mils	25	2	30	4	45	2.5	18	3.5	22
20 mils	36	3	19	2	40	4	10	4	
Paint No. 45% BVC	91	91	89	89	85	85	87	87	
20 mils	20	6	20	8	18	5	15	14	
30 mils	30	12	12	9	35	3	18	14	
Special Reflectance									
Paint No. 0% BVC	90	90	88	88	84	84	86	86	90
10 mils	10	10	13	9	9	7	13	9	
15 mils	17	4	15	9	18	9	11	8	18
20 mils	26	5	26	9	18	8	11	9	
Paint No. 45% BVC	91	91	89	89	85	85	87	87	
20 mils	13	10	12	9	12	11	10	10	
30 mils	16	11	12	9	15	11	11	10	

[x] Integrity determinations were based on chipping with exceptions noted.

[xx] These paints showed integrity failure by erosion or smearing rather than chipping.

TABLE III

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
9 WEEKS OBSERVATIONS

Beaded-Unbeaded	Reg. Alkyd B	Reg. Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
Integrity									
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	5^{x}	2^{x}	2^{x}	3^{x}	3^{x}	3^{x}	2^{xx}	2^{xx}	
15 mils	5^{x}	1^{x}	5^{x}	3^{x}	5^{x}	4^{x}	3^{xx}	3^{xx}	8^{xx}
20 mils	6^{x}	1^{x}	8^{x}	3^{x}	6^{x}	3^{x}	4^{xx}	4^{xx}	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	6^{x}	6^{x}	6^{x}	5^{x}	6^{x}	4^{x}	6^{xx}	7^{xx}	
30 mils	6^{x}	5^{x}	5^{x}	5^{x}	5^{x}	5^{x}	7^{xx}	7^{xx}	
Hunter Night Visibility^{o}									
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	7	1	10	2	1^{o}(0)	20^{o}(0)	2	1	
15 mils	11	1	15	17	2.5^{o}(5)	27^{o}(4)	2	1	11
20 mils	24	1	2	4	2^{o}(4)	2^{o}(4)	2	3	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	9	6	10	5	12	6	9	9	
30 mils	12	8	12	10	16	5	9	9	
Special Reflectance									
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	10	8	9	7	6	7	9	7	
15 mils	11	6	11	6	14	12	9	9	15
20 mils	18	6	12	8	18	12	11	11	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	11	12	13	12	10	11	9	10	
30 mils	13	9	12	11	14	14	9	10	

x Integrity determinations were based on chipping with exceptions noted.

xx These paints showed integrity failure by erosion or smearing rather than chipping.

o The Hunter Instrument obviously gave some false readings.
Figures in parenthesis are based on equivalents from the special reflectometer and converted to Hunter readings based on previously prepared correlation charts.

TABLE IV

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
10 WEEKS OBSERVATIONS

Beaded-Unbeaded	Reg. Alkyd B	Reg. Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
					Integrity				
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	4^{x}	3^{x}	3^{x}	4^{x}	3^{x}	3^{x}	2^{xx}	2^{xx}	
15 mils	4^{x}	2^{x}	4^{x}	3^{x}	3^{x}	3^{x}	$4^{\boxtimes}$	$4^{\boxtimes}$	7^{x}
20 mils	6^{x}	2^{x}	6^{x}	2^{x}	3^{x}	2^{x}	$4^{\boxtimes}$	$4^{\boxtimes}$	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	4^{x}	4^{x}	4^{x}	4^{x}	4^{x}	3^{x}	$3^{\boxtimes}$	$3^{\boxtimes}$	
30 mils	4^{x}	3^{x}	4^{x}	4^{x}	3^{x}	3^{x}	$4^{\boxtimes}$	$4^{\boxtimes}$	

No observations for night visibility were made at this time.

x Integrity determinations were based on chipping with exceptions noted.

xx These paints showed integrity failure by erosion or smearing rather than chipping.

⊠ Paint stripes show chipping and erosion.

TABLE V

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
17 WEEKS OBSERVATIONS

Beaded-Unbeaded	Reg. Alkyd B	Reg. Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
					Integrity				
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	2[x]	2[x]	1[x]	2[x]	1[x]	2[x]	1[xx]	1[xx]	5[x]
15 mils	2[x]	1[x]	3[x]	3[x]	2[x]	2[x]	2[xx]	2[xx]	
20 mils	2[x]	1[x]	4[x]	2[x]	1[x]	1[x]	2[xx]	3[xx]	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	2[x]	2[x]	3[x]	2[x]	2[x]	1[x]	1[xx]	1[xx]	
30 mils	2[x]	2[x]	3[x]	2[x]	1[x]	1[x]	2[xx]	2[xx]	
					Hunter Night Visibility				
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	3	0.4	9	2	1	1	4	1	
15 mils	7	1	7	2	12	2	2	5	12
20 mils	11	1	18	2	18		3	2	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	9	7	9	6	12	9	16	10	
30 mils	12	6	13	10	14	12	11	13	
					Special Reflectance				
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	6	7	8	8	5	7	9	9	
15 mils	5	8	7	8	8	9	9	12	11
20 mils	8	5	15	10	9	8	11	12	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	8	8	7	9	7	8	10	8	
30 mils	10	9	9	9	8	6	8	9	

[x] Integrity determinations were based on chipping with exceptions noted.

[xx] These paints showed integrity failure by erosion or smearing rather than chipping.

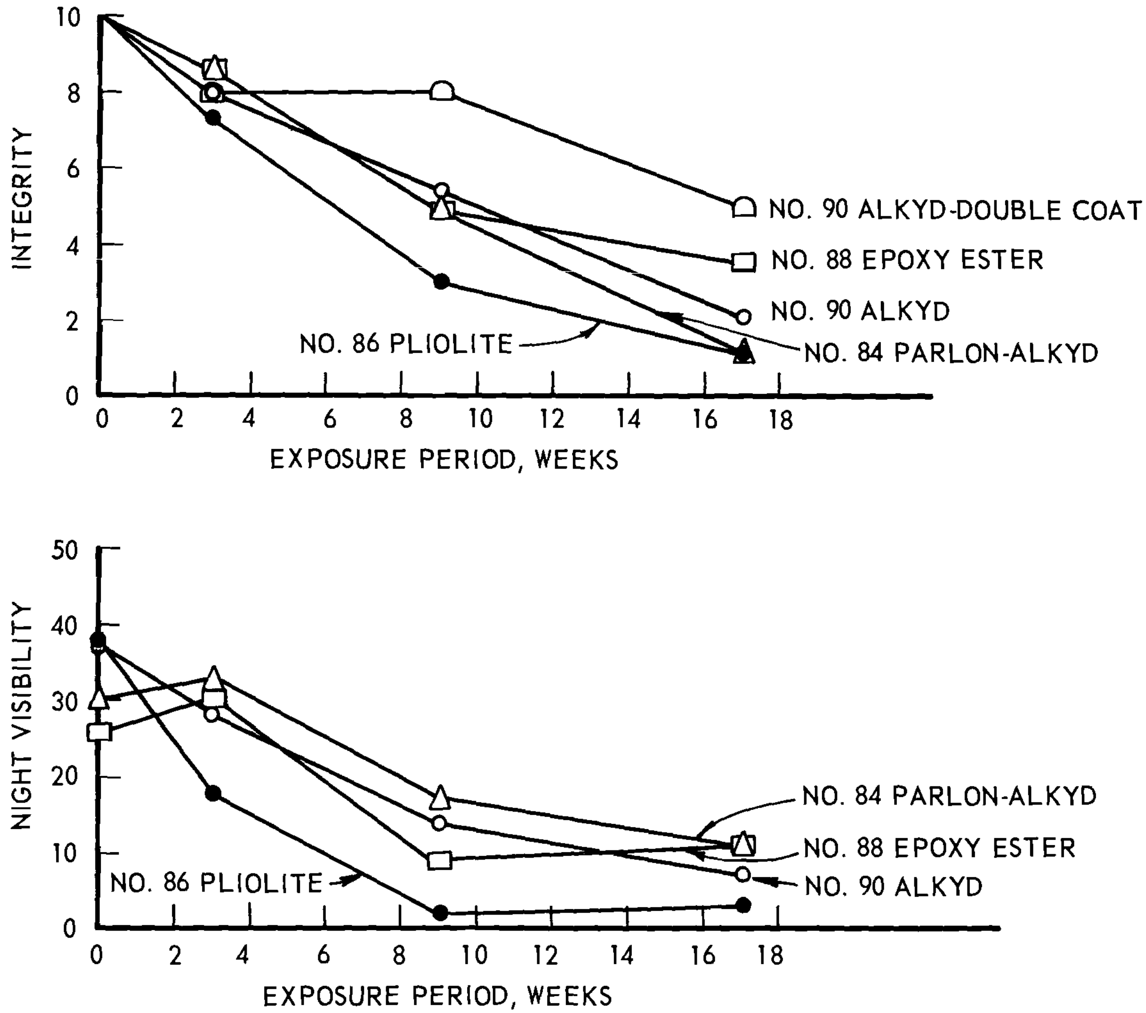

Figure 1. Integrity and Night Visibility versus Exposure Time.
Average Value for 10, 15, and 20 mil Films.

Figure 2. Alkyd Double Coat at 17 Weeks.

Environmental Extremes. The observations made at 10 weeks following an ice storm and use of tire chains on the roadway were intended to assay the immediate effects of such environmental extremes. The condition of the test stripes of all paints without the "bead in" modification was not significantly different over a one week interval with the intervening ice storm. Slightly more deterioration was observed with the "bead in" paints. It should be noted that film failures were already well developed at this time, and immediate effects might be less apparent than on new stripes. Nevertheless, the observers were surprised at the small changes in appearance.

Summary. The foregoing observations are summarized as follows:

1. Series III has exhibited higher wearing rates than previous series.
2. No large extremes in relative paint performance were observed, but a two-coat system was outstanding.
3. "Bead on" beading enhances paint durability, but "bead in" paints were significantly superior only in night visibility retention.
4. When the mode of paint failure is chipping, increased film thickness does not enhance performance as much as when an erosive mode of failure occurs.
5. An ice storm produces no catastrophic paint failure.

III. Other Activities

Further work on the wet night visibility concept has been deferred to permit equipment and techniques under development on Project No. A-802 to become available for this purpose. Certain hot melt compositions may provide a particularly effective binder for retroreflective granules of the sizes required.

Some additional theoretical study of tire-surface dynamics has been undertaken in an effort to gain a more quantitative understanding of the pressure wave theory discussed in Quarterly Report No. 13. It became apparent that this subject could not be properly developed within the scope of the present project. This work has at least imparted a qualitative conception of the nature of the limitations of presently available traffic paint testing devices and of the physical requirements for dynamic simulation.

IV. Future Work

Highway testing has been completed, and special reports covering this entire activity are in preparation.

The accelerated wear tester has demonstrated a satisfactory capability for evaluating erosive wear. Experimental work is continuing on evaluation of chipping-type paint failure.

Formulation studies have been inhibited by the obvious limitations of the accelerated wear tester; however, further work on novel vehicles has been planned.

Respectfully submitted,

[redacted]

W. H. Burrows, Head
Industrial Products Branch

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

January 18, 1965

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Report No. 14
Quarterly Progress Report No. 13
Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 October 1964 through 31 December 1964

Gentlemen:

Project activities have included the following topics: (1) accelerated wear testing, (2) highway tests, (3) night visibility media, and (4) other activities. A discussion of each of these activities follows:

I. Accelerated Wear Testing

During the subject period, wear testing has been confined to three selected machine operating conditions as described below:

	Operating Conditions		
	I	II	III
Wheel Speed, RPM	100	40	10
Wheel Load, lbs.	40	40	40
Water Cycle:			
On, min.	Continuous	20	5
Off, min.	-	10	25
Abrasive Feed, g/hr.	17	17	none

Condition I produces very rapid erosive wear of traffic paint films so that a typical test is completed in about 2-3 hours. Because of the continuous wet condition, and because of the very rapid erosion, it is not feasible to observe bead retention with this test.

Condition II yields erosive film failure similar to that of Condition I, but over a longer time period. The wetting-drying cycling provides dry periods for checking bead retention by reflectance. When the essential equivalence of the tests became apparent, Condition II was selected as the more useful test. A typical plot of integrity versus test time is shown in Figure 1.

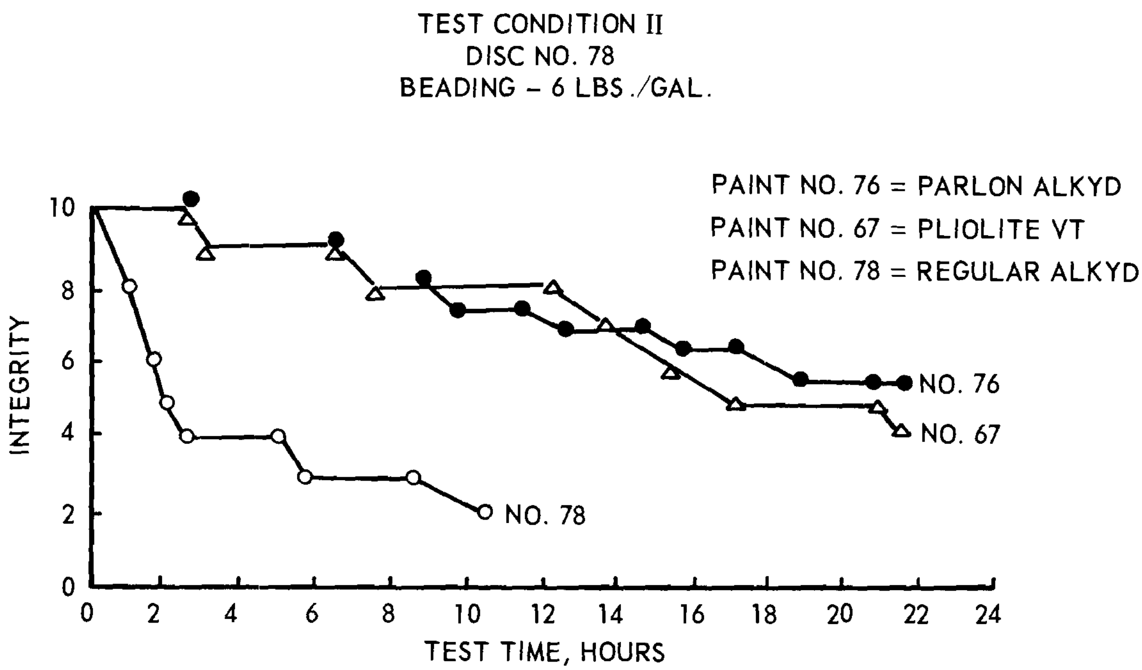

Figure 1. Accelerated Wear Test Results.

Condition III is a much slower test. Testing periods of 200 hours have not yielded failures with some paints. Failure of paints on this test is associated with cracking, spalling, chipping, or peeling, rather than erosion. During the longer dry cycle periods of this test, the abrasion wheel develops a slight tack which imparts a distinct shearing and lifting force to the paint film. By the elimination of abrasive and reduction of wheel speed to a practical minimum, it was possible to sufficiently retard the erosive effects that these other modes of film failure could be observed. A specimen of data obtained from a Condition III test run is given in Table I.

Test work is being continued at full capacity on the accelerated wear tester to accumulate adequate data to fully define the capabilities of the test methods. However, it is necessary now to recognize that the accelerated wear tests are not fully correlating with current highway tests. At the same time, it is believed that an understanding of the nature of the differences has been gained, and an improved conception of the physical requirements for traffic paints has been realized. These ideas will be developed more clearly in the light of current highway test observations as described below.

II. Highway Tests, Series III.

This series of highway tests was placed on the Atlanta Northeast Expressway (I-85) in the outer northbound lane about 1/4 mile north of the Piedmont Road exit on November 12, 1964. The tests involved four different paint types at three wet film thicknesses (10, 15,20 mils) beaded and unbeaded. In addition, these paints were formulated with "beads in" at 45% BVC and tested at 20 and 30 mils wet thicknesses both with and without drop-on beading. Finally, a single stripe was placed as a two-coat application of #90 alkyd. Both coats were beaded normally, the second coat applied 20 minutes following the first. Test results at one month are presented in Table II. Because of the immaturity of these tests, a detailed discussion is not justified at this time; however, wear has already progressed sufficiently to justify some significant observations.

Wear has been very rapid for this series -- at least as rapid as Series II. Film failure is by chipping in almost all cases. #86 Pliolite is the exception which shows almost no chipping. Beads-on films are invariably superior to unbeaded films in integrity, but the effect of increasing film thickness is not so marked. Beads-in formulations have not yet displayed any distinct superiority to the same formulations without such beading. Most significantly, while the #90 alkyd has exhibited some chipping failure, its performance is generally comparable to the other paints in this series, and certainly does not show the distinct inferiority displayed in recent accelerated wear tests.

These observations have stimulated further efforts to rationalize mechanisms of film failure. Among the three series of highway studies that have been conducted, the results have shown a progressive shortening of film durability and a

TABLE I

TEST RUN OF CONDITION III

Test Time (hrs)	Paint No. and Type	Observations, Disc No. 77
1	78 Alkyd	Beaded and Unbeaded - Rapid development of heavy smear effect.
4	76 Parlon Alkyd	Unbeaded - Very fine hairline cracks
22	76 Parlon Alkyd	Unbeaded - Substantial cracks
72	67 Pliolite VT	Beaded - Very fine hairline cracks
211*	76 Parlon Alkyd	Beaded and Unbeaded - Heavy spalling, moderate chipping.
	67 Pliolite VT	Beaded and Unbeaded - Light cracks

*Test terminated at 211 hrs.

TABLE II

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
ONE MONTH OBSERVATIONS

(Beaded-Unbeaded)	Reg Alkyd B	Reg Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
			Integrity*						
Paint No.	90	90	88	88	84	84	86**	86**	90
0% BVC									
10 mils	7	4	8	7	7	6	6	7	
15 mils	9	4	9	6	9	8	7	9	8
20 mils	8	5	9	7	10	8	9	9	
Paint No.	91	91	89	89	85	85	87**	87**	
45% BVC:									
20 mils	8	7	9	8	7	8	7	8	
30 mils	9	7	7**	7**	10	9	8	8	
			Hunter Night Visibility						
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC:									
10 mils	26	3	40	4	13	3	20	3	
15 mils	25	2	30	4	45	2.5	18	35	22
20 mils	36	3	19	2	40	4	10	4	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC:									
20 mils	20	6	20	8	18	5	15	14	
30 mils	30	12	12	9	35	3	18	14	
			Special Reflectance						
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC:									
10 mils	10	10	13	9	9	7	13	9	
15 mils	17	4	15	9	18	9	11	8	18
20 mils	26	5	26	9	18	8	11	9	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC:									
20 mils	13	10	12	9	12	11	10	10	
30 mils	16	11	12	9	15	11	11	10	

* Integrity determinations were based on chipping with exceptions noted.

** These paints showed integrity failure by erosion or smearing rather than chipping.

trend to failure by chipping rather than abrasion. Despite the numerous possible sources of variation in results, it is believed that the primary variable is the condition of the concrete highway surface. The highway surface apparently has become increasingly contaminated during the three year period, and perhaps the locations of Series II and III were in areas of higher initial contamination. In any case, when a good quality traffic paint exhibits chipping failure after one month's field exposure, it is almost certain that initial adhesion was inadequate and the failure was induced almost entirely by mechanical stresses imparted by tire action.

How, specifically, does tire action impart stresses affecting adhesion? Qualitatively, when a tire rolls over a painted surface it imparts first a downward pressure on the film immediately followed by a release of pressure and finally an area of low pressure (vacuum) along the parting line of the paint-tread interface. At high speeds this vacuum might approach a full atmosphere, and rapid air expansion under the film could have an explosive upward pressure effect. Under wet conditions, the tire-paint parting would involve the splitting of a water film, and the upward tensile force on the paint film required to induce this splitting would not be limited to one atmosphere of pressure. It will now be evident that the pressure on a paint film under a moving tire will be distributed as shown in Figure 2. It is certainly not difficult to imagine that a progression of these pressure waves over a paint film could finally induce loss of adhesion.

To what extent may one relate this theory to observed paint performance? First, the importance of adhesion to traffic paint durability is further emphasized in terms of applied forces which can destroy the bond. A general experimental observation that hard films are more susceptable to chipping failure than softer films is consistent with the conception that pressure waves would induce greater stress concentrations in non-compliant rigid films so that much greater adhesion might be required to prevent chipping failure. Field results suggest that, in general, the necessary superior adhesion has not been realized.

Second, the theory provides a mechanism to explain the relatively rapid flaking of Series II and III Highway Tests if one assumes poorer initial adhesion for these tests. Finally, the source of correlation difficulties between the highway tests and the laboratory wear tester now seem apparent. A means must be found to gain an improved simulation of the pressure wave effect on the wear tester if correlation is to be improved.

A more detailed study of the pressure wave theory and its relation to the wear tester and to the physical property requirements of traffic paints is being made. From an improved understanding of the pertinent surface dynamics, the design and testing of traffic paints for heavy service conditions may ultimately be based on a sound theoretical model rather than on naive empirical simulations.

III. Night Visibility

A special report was issued in December describing activities in this area through the month of November 1964. This report describes a novel retroreflective granule for use in traffic markings. This granule, which may be of tetrahedral or other suitable shape, elevates the retroreflective medium (glass beads) in such manner as to overcome the obliterating effect of water films encountered in wet weather. Photographs included in the report illustrate the high contrast in visibility obtainable with this material, as opposed to conventional reflective media.

A survey of the patent literature disclosed a prior art consisting of the following patents: Palmquist #2,294,930; Weber #2,345,644; Flood #2,355,430; Palmquist et al #2,407,680; Wynn #2,865,266; and Palmquist et al #3,043,196. Only Flood, Wynn and Palmquist (3,043,196) show the use of non-spherical granules in traffic marking paint. Flood and Wynn are confined to specularly reflecting or diffusing granules (crystal faces), while Palmquist discloses granules of irregular shape coated with glass beads. The last quoted reference would, therefore, seem to offer the only interference with the idea incorporated in Tooke's report.

Since the fundamental conception is anticipated in the patent literature, it has appeared appropriate to curtail the developmental work suggested in the report and confine further investigations to selected field evaluations. Some additional funding may be required to conduct these evaluations, and a proposal for this work is being prepared.

IV. Other Activities

An investigation of certain formulation details of the Georgia Specification Traffic Paints was discussed in Monthly Progress Report No. 13. This work was concerned primarily with the relations of vehicle solids with paint consistency and appropriate specification limits. The findings indicated that a slight increase in the specified minimum vehicle solids would be justified.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

Approved:

[redacted]

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

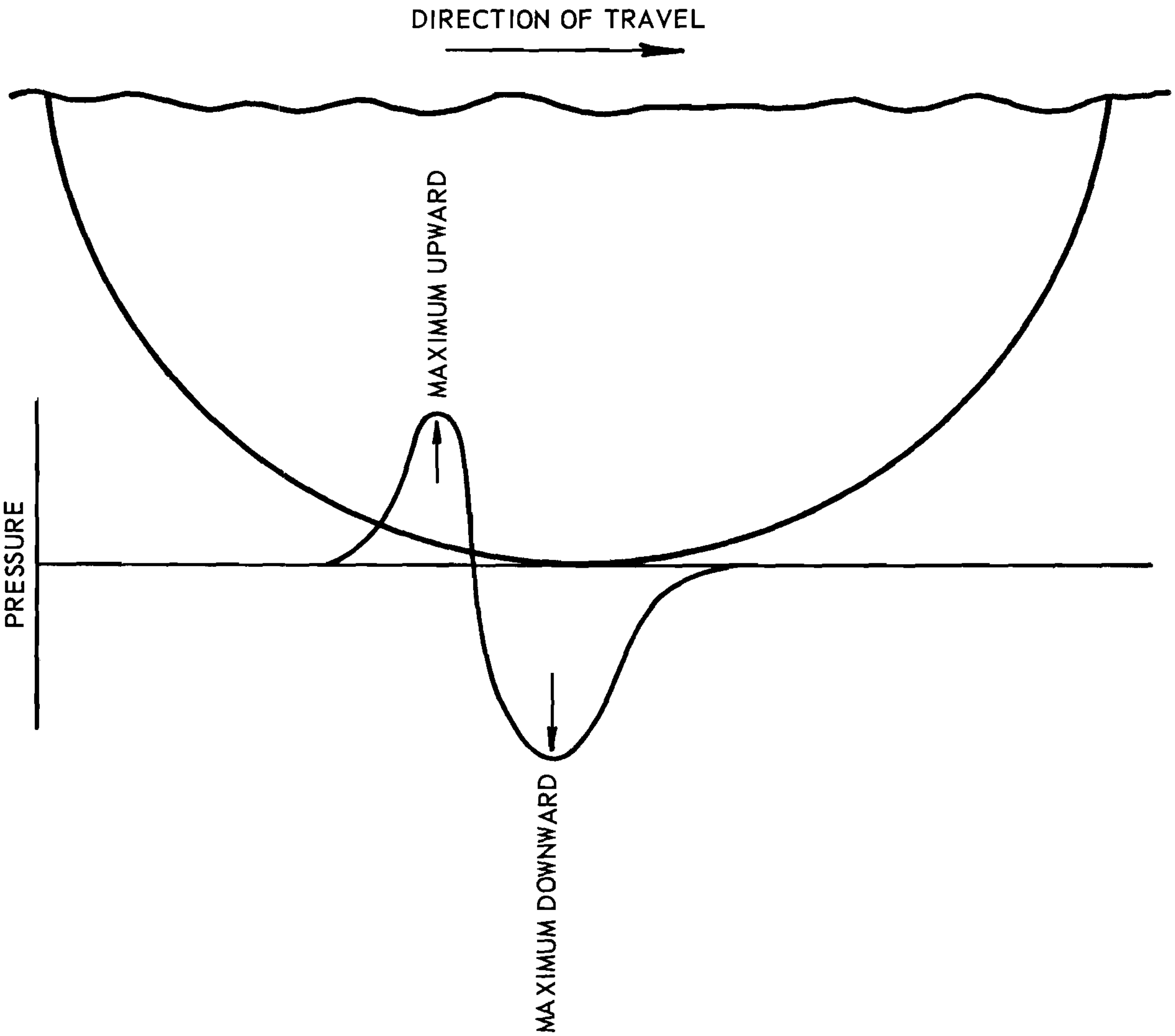

Figure 2. Pressure Distribution Under a Moving Tire.

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July 6, 1965

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State Highway Department of Georgia
2 Capitol Square, S. W.
Atlanta, Georgia 30302

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Quarterly Progress Report No. 15
Georgia Tech Project No. B-210, "Use of Radioisotopes in Development of Test Methods and Formulations for Traffic Paints." Covering the period 1 April 1965 through 30 June 1965

Gentlemen:

Project activities during the indicated quarterly period included:

1. Completion of a study of operating variables on the accelerated wear tester.

2. Physical characterization of paints tested on the wear tester and included in highway test Series III.

3. Analysis of findings from the foregoing work and drafting of Final Technical Reports for the entire project.

This work is summarized only briefly, as it will be covered in detail in the final reports.

I. Accelerated Wear Testing

The effects of substrate variations on the chipping mode of paint failure have been evaluated. The response of the several paints to these substrate variations was very pronounced.

Table I shows the testing time of each run together with the final ASTM rating. In general, the test discs were run until definite distinctions in performance among the four paints could be observed. Thus, the testing time provides an approximation of the relative "adherability" of the various substrates. The ASTM ratings, shown in parentheses, indicate the relative performance of the paints.

Comparison of values within a column indicates that the texture, the permeability and the degree of contamination of the substrate exert a major influence on paint performance. Comparisons within the rows reveal that substrate variations alter the ordering of relative paint performance. The great enhancement of paint performance on a permeable substrate, as represented by clean transite, is possibly the most significant single observation. While this study has not solved the problem of chipping-adhesion evaluation, it has demonstrated the importance of several substrate effects.

II. Physical Characterization Tests

In an effort to gain further understanding of relationships of film properties to accelerated wear and to highway test performance, selected paint film tests were run on the current set of paints. Procedural details on these tests will be discussed in the final report. Results are shown in Table II, and analysis and correlation of the findings are now in progress.

The following preliminary observations are significant:

1. With a few exceptions, these paints exhibit a rather narrow range of film properties; that is, they are not markedly different in physical characteristics. This is consistent with their generally similar highway performance.

2. The somewhat higher initial hardness and adhesion of the S/B resin paint (No. 86) seems to account for its relative superiority in accelerated wear testing. However, its lack of outstanding highway performance may well result from the high loss of elongation and loss of impact resistance experienced with accelerated ageing.

3. The standard alkyd paint compares favorably with other formulations in initial and aged properties. This is consistent with highway observations, but not with its relatively poor showing on accelerated wear tests. Qualitative evaluation* shows the standard alkyd to be definitely the softest in initial properties, which would account for its poor resistance to the shearing action in the accelerated test.

4. The epoxy ester paint exhibits a superior overall combination of physical test properties. It also exhibits commendable performance on the road and on the accelerated wear test.

5. The chlorinated rubber-alkyd is very similar to the epoxy ester in nearly all respects.

If the foregoing observations should be fully confirmed by further data analysis, a much clearer understanding of the relationships of highway ageing, accelerated wear, and physical test properties of these traffic paints will have been gained.

*The original hardness (7 days air dry) of most of these paints is below the lower limit of the Pencil Hardness Test.

TABLE I

ACCELERATED WEAR TESTING* - SUBSTRATE EFFECTS

Substrate	Time of Test, Hrs. and ASTM Rating** Std. Alk. #90	Chl. Rub.-Alk. #84	Epox. Est. #88	S/B Resin #86
Concrete	49 (6)	49 (10)	49 (9)	49 (9)
Concrete, wax treated	26 (4)	27 (9)	27 (4)	29 (1)
Plain Glass	9 (1)	9 (5)	9 (5)	9 (10)
Plain Glass, wax treated	1 (5)	1 (10)	1 (9)	1 (10)
Ground Glass	21 (1)	21 (9)	21 (9)	21 (9)
Ground Glass, wax treated	1 (4)	1 (10)	1 (10)	1 (9)
Transite	110 (10)	110 (10)	110 (8)	110 (9)
Transite, wax treated	3 (5)	3 (2)	3 (1)	3 (4)

*Test Condition V. (Wheel load - 40 lbs., Speed - 40 RPM, no abrasive.)
**ASTM Rating is in parenthesis.

TABLE II

PHYSICAL TESTS OF HIGHWAY PAINTS

Paint No. and Type	Film* Condition	Pencil** Hardness	Adherence No.	Mandrel Test Crack Dens.	Mandrel Test Elongation %	Reverse Impact Test in.-lbs.
90	A	< 5B	4.4	10	13.8	8
Std.	O	H	5.3	12	8.2	8
Alkyd	Change	+> 7	+0.9	+2	-5.6	0
84	A	< 5B	6.2	12	7.1	4
Chl. Rub.	O	F	3.6	13	7.1	14
Alkyd	Change	+> 6	-2.6	+1	0	+10
88	A	< 5B	7.0	8	11.6	26
Epoxy	O	F	6.7	8	8.2	26
Ester	Change	+> 6	-0.3	0	-3.4	0
86	A	5B	10.0	14	10.5	4
S/B	O	H	4.6	14	5.8	2
Resin	Change	+7	-5.4	0	-4.7	-2

*Film Condition:
A = Air dried 7 days
O = Air dried 7 days, then baked 24 hrs. at 80° C.

**Test pencils increase in hardness in the order: 5B, 4B, 3B, 2B, B, HB, F, H

III. Final Reports

All experimental work has been concluded, and current project activities are confined to data analysis and preparation of final reports. These final reports have been organized into three separate sections as follows:

Section I. Preparatory Work and Highway Test Series I

Section II. Highway Test Series II and III

Section III. Accelerated Wear Testing and Correlations

Editorial work is nearing completion on Section I, and data analysis and rough drafts are in progress on Sections II and III.

Respectfully submitted,

[redacted]

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ANNUAL REPORT NO. 1

PROJECT NO. B-210
HPS-1(60)

USE OF RADIOISOTOPES IN DEVELOPMENT OF TEST METHODS AND FORMULATIONS FOR TRAFFIC PAINTS

By

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COVERING THE PERIOD
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This report contains 30 pages.

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ABSTRACT

An extensive literature search has been made, touching on all phases of the work of this project. Nine paint formulations have been prepared or acquired for testing, including basic types presently in use in large quantity, new types presently under consideration for federal specifications, and types still in the developmental stage. A thickness gage, operating on the principle of backscatter of beta radiation, has been fabricated and operated successfully. A wear test machine has been designed and constructed. Together with test slabs of concrete and transite, this machine has been used for wear tests on a number of the above mentioned formulations. A paint stripe applicator, designed to provide a flow of paint to a spray nozzle in such manner that the flow is metered by the rate of traverse of the applicator, has recently been completed for use in field tests. It is anticipated that field tests and laboratory studies will be conducted in parallel during the coming year as a means of developing correlations between the two.

I. INTRODUCTION

The original objectives of this research program were as follows:

1. Development of a device, utilizing radioisotopes, for the purpose of measuring the dry film thickness of highway paints, both in the laboratory and in the field.

2. Development of laboratory wear tests that can be correlated with the actual wear of traffic paints in highway use.

3. Development of special highway paint application equipment utilizing radioisotopes. This equipment would control the thickness of application and position the fresh stripe directly over the existing stripe.

4. Formulation of traffic paints, utilizing the devices and findings of the foregoing studies, to improve the performance of traffic paints.

Accomplishments during the first year of this project have included the following:

1. Design, construction, and operation of a film thickness gage based upon the principle of backscatter of beta radiation. This device has been successfully used in the measurement of dry film thickness of paint stripes in the laboratory.

2. Design, construction, and operation of a wear test machine, using an eraser stock tire as an abrading element, operating against a test panel of concrete or transite painted with the test paint.

3. Design and construction of a paint stripe applicator. This device meters paint in proportion to its rate of traverse, the paint being applied as a stripe by a spray mechanism. The device is now being tested and will later be used in field tests.

4. Preparation or procurement of nine paint formulations for testing. These include five formulations which are presently in volume use, two which are under consideration for federal specifications, and two epoxy formulations. Epoxy paints are especially outstanding in adhesion and toughness.

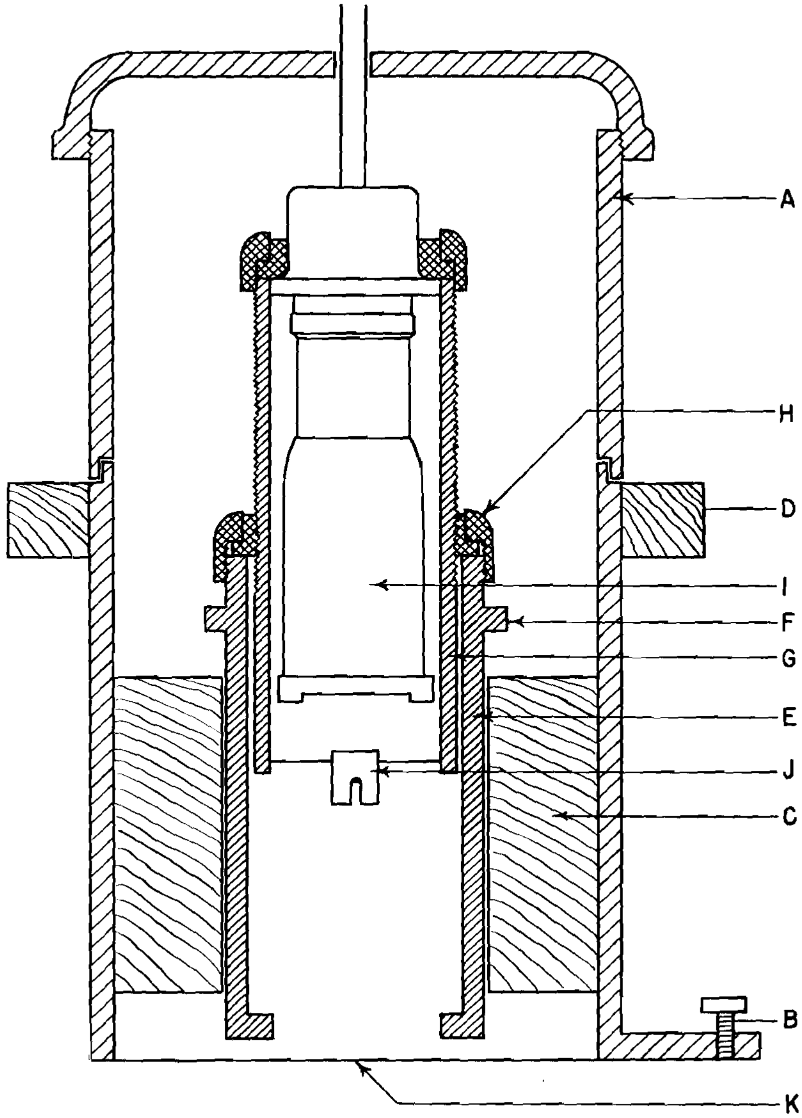
5. An extensive study of the literature pertaining to all phases of this research program. A number of pertinent references from this study are included in Appendix B.

The work of this program to date was covered in some detail in Quarterly Report No. 3, dated February 7, 1962. Since that time, additional tests have been conducted on the wear test machine, the paint stripe applicator has been completed, and two additional paint formulations (the epoxies) have been added.

Specific details of the year's work in each phase are given in the following sections.

II. BETA-RAY FILM THICKNESS GAGE

The instrument developed in this phase of the program is patterned after a similar device employed by B. W. Pocock (19, 20). A cross-section diagram is shown in Figure 1. Figure 2 shows the device attached to a scalar and positioned on a test panel as it is used in measuring the thickness of a paint film. Operation of the device depends upon a difference in the back-scattering characteristics of the paint film and the substrate. The greater the difference in count from the paint and that from the substrate, the more accurate the measurement of film thickness will be. Table I shows the number of counts per minute obtained from various substrates, paint films, and wet paints. The difference of 485 counts between white paint and transite



1. An outer casing of steel (A) has three adjustable pedestal screws (B) for positioning the base of the case relative to the painted surface. A ring of hardwood (C) inside this casing serves to support the mounts of the Geiger tube when the gage is not resting on a surface. Hardwood handles (D) are provided on each side of the case.

2. A plastic tube (E) fits loosely into the hole of the wooden ring, so that the bottom end of the plastic rests on the painted surface. When the gage is lifted, a shoulder (F) on this plastic member prevents its slipping on through the ring.

3. A second plastic tube (G) fits concentrically into the top of the first and is rigidly positioned by means of a lock ring (H). This tube supports the Geiger tube (I) and the beta radiation source (J). Positions of both may be adjusted vertically, so as to obtain the maximum sensitivity from the instrument.

Radiation from the source (J) strikes and penetrates the painted surface (K). This radiation is scattered by the matter with which it comes into contact in the paint film, some of it finding its way back out of the paint film and up to the Geiger counter. Each ray that strikes the counter registers one count. Counts from various materials range from 138 per minute for air (i.e., no surface) to 17,346 per minute for lead.

Figure 1. Cross Section of Beta Backscatter Thickness Gage.

Figure 2. Complete Measuring Unit - Gage and Scaler.

TABLE I

BETA BACKSCATTER FROM VARIOUS SUBSTRATES

Substrate Material	Counts Per Minute
None (background)	138
Plywood	1,982
Plate Glass	4,210
Aluminum	4,970
Steel	8,730
Lead	17,346
Transite	4,415
Concrete	4,265
Liquid Paints:	
No. 1 Ga., yellow	6,840
No. 2 Alkyd, white	2,192
No. 5 Lacquer, white	2,018
Dry Paint Films on Transite:	
No. 1 Ga., yellow, 15 mils	8,717
No. 2 Alkyd, white, 15 mils	4,027

is not as great as that between transite and yellow paint: 4,302; consequently, measurement of yellow paint film thickness is much more accurate by this method than is measurement of white paint film thickness.

In practice, a curve is prepared for each type paint on each substrate, showing variation of counts per minute with paint film thickness. Readings from the scaler are then immediately translated into film thickness by reading from the curve. Figure 3 shows a calibration curve plotted from measurements made on Georgia yellow traffic paint. The curve starts at the value for the bare substrate and approaches asymptotically the value for infinite thickness of the paint film.

Initial studies with the thickness gage have included various substrates, surface variations of concrete, surface variations of transite, effects of position of sensing head on painted transite, effects of film thickness of Paint No. 2 on transite, effects of film thickness of Paint No. 3 on transite, and effects of wear. Data tabulated in these studies are included in Quarterly Report No. 3 of this project.

The scaler presently being used with this gage is adaptable only to laboratory studies, since it requires a 115 volt A.C. source. When the time comes for field tests, it will be necessary to use a portable scaler with this gage. It is hoped that a loan of such equipment may be negotiated with one of the manufacturers at that time.

III. WEAR TEST MACHINE

The wear test machine developed for this program is patterned after the machine described in Federal Specification TT-P-115A, and is shown in Figure 4. It is believed that this machine simulates closely the dynamics of vehicle tire wear on highway surfaces. Means are provided for adjusting the intensity of tire wear. In addition, complete environmental control of the test surface is possible with slight modifications, providing for conditions of heat, cold, wetness, dryness, freezing and thawing.

During early tests, certain defects in the abrading action became apparent. Wear was nonuniform over the face of the abrading wheel, and a ridge

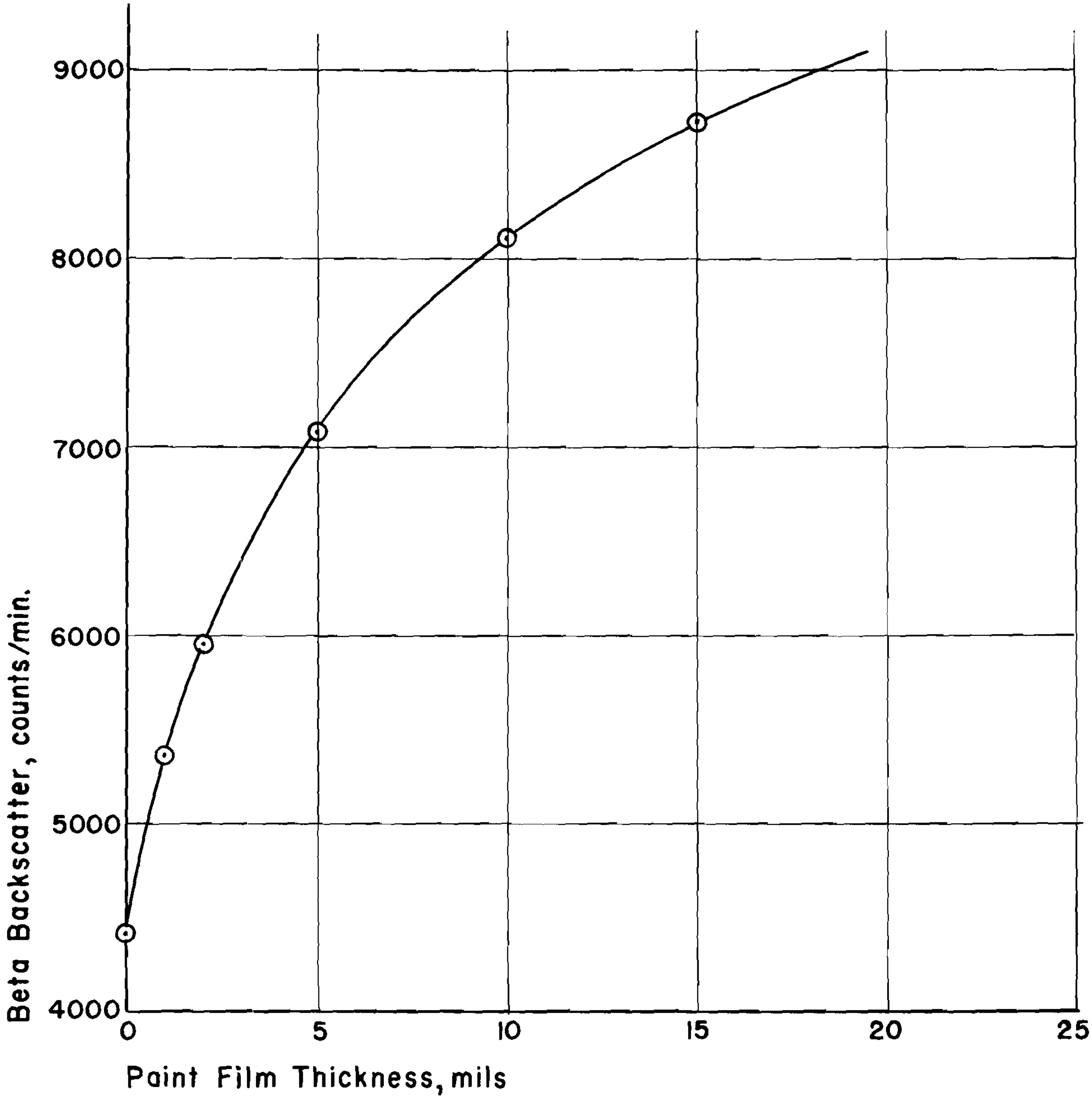


Figure 3. Counting Rate vs. Thickness for Georgia Yellow Traffic Paint on Transite.

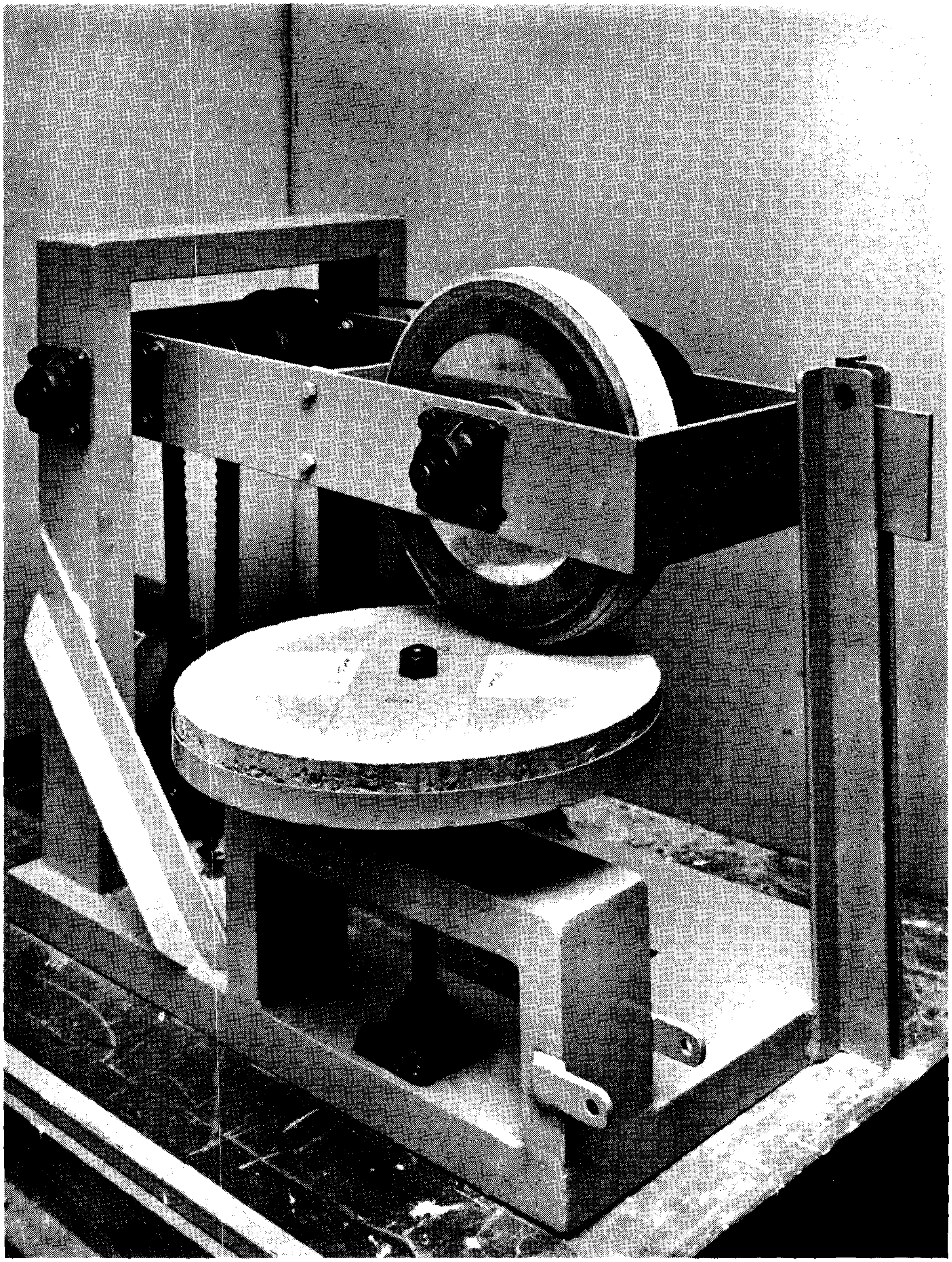


Figure 4. Wear Test Machine.

of abraded paint particles built up in the middle of the abrading wheel track. This condition was later corrected by the addition of a vacuum attachment to the abrading wheel. This matter is discussed in detail in Quarterly Report No. 3.

Results obtained with the present machine are as follows:

1. The abrading wheel wears fairly uniformly on a smooth surface, such as transite. (Note the left panel of Figure 5.)

2. The wear pattern on concrete is much less regular, largely because of unevenness in the surface and premature loss of paint on high spots through the action of the abrading wheel. (Note the right panel of Figure 5.)

3. Abrasion wearing is usually much more rapid on a wet surface than on a dry surface. For example, paint No. 2 was observed to be intact at 10,000 cycles dry, but worn through at 2600 cycles wet. (Research Record Book 1407, pp. 23, 24)

4. The importance of paint film thickness as a major factor in wear assessment is confirmed by these tests. (Note right and left panels of Figure 5. Paint stripes at 6:00, 3:00, 12:00, and 9:00 o'clock consist of 2, 4, 6, and 8 spray passes of paint respectively.)

IV. PAINT STRIPE APPLICATOR

Many investigators have made sincere efforts to attain prescribed film thicknesses in the field testing of highway paints, but with questionable success. Commercially available application equipment does not lend itself to the precise control of film thickness, especially when paints of varying rheological characteristics are being applied. The most acceptable solution

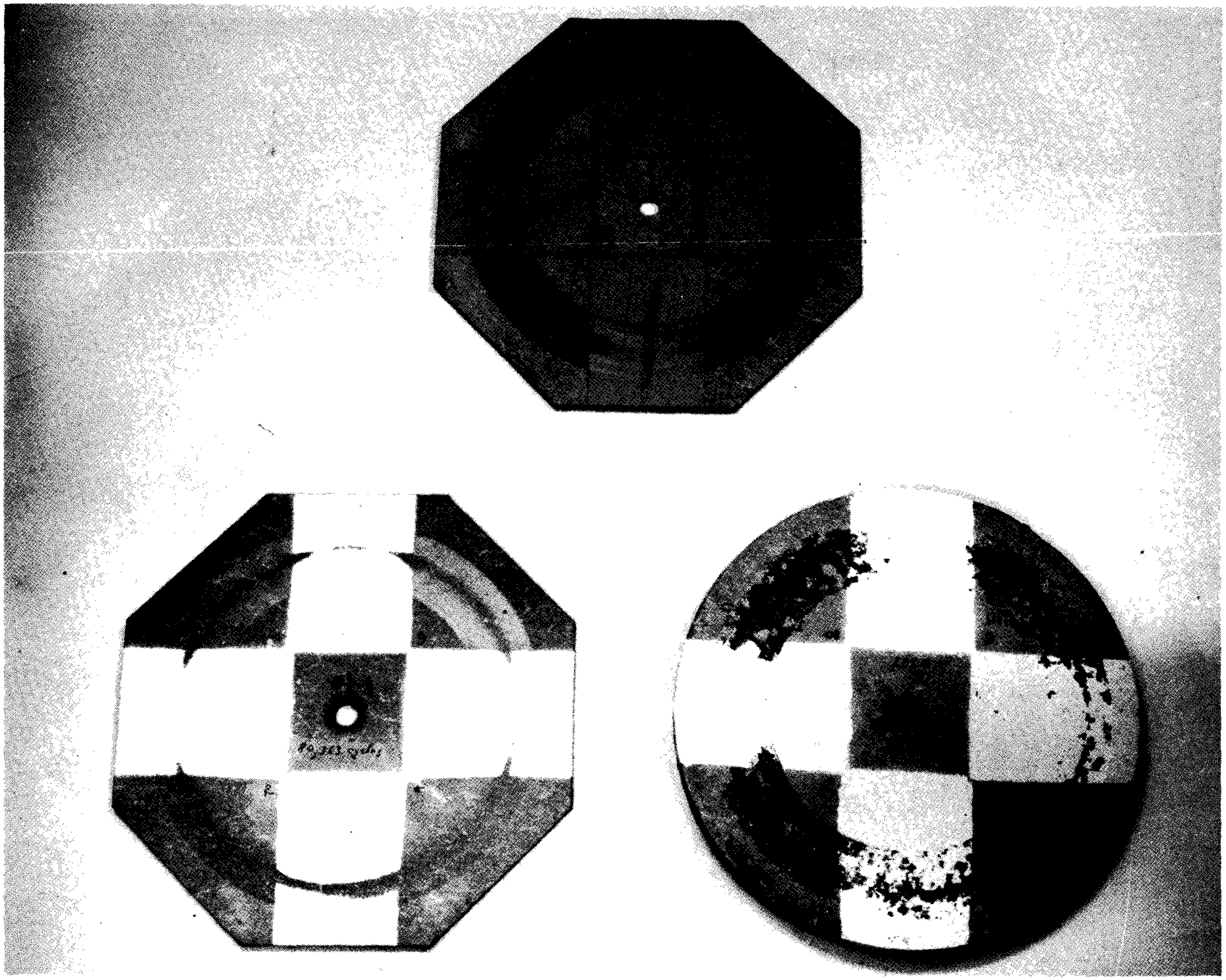


Figure 5. Wear Test Panels. (Top Panel - Ga. Specification 41A, Yellow on Transite. Left and Right Panels - TT-P-115a, White on Transite and Concrete Respectively.

to the problem appears to be an applicator machine capable of metering paint to a spray head in precise proportion to the traverse of the spray head along the highway surface. To accomplish this it is necessary that the paint be delivered by positive displacement, rather than by air pressure. A piston and cylinder, geared to the wheels of the applicator carriage, is the simplest and most reliable device for this purpose.

For comparative paint tests, it was decided that a capacity for about 30 feet of continuous line would be adequate. Together with the paint stripe width and maximum thickness, this factor determined the volume of the cylinder required, thus establishing design dimensions for the machine.

A photograph of the machine which has been constructed is shown in Figure 6. Paint is charged to the vertical cylinder through the funnel at the top. The cock below the funnel is closed, and the piston is advanced with the gun nozzle open until all air is purged from the cylinder and material line, and paint is being delivered to the gun.

As the carriage moves forward, front axle rotation is transmitted through a speed reducing pulley and belt system to a "floating" pinion on the rear axle. This pinion drives forward a rack, which is surmounted by a variable pitch inclined brass bar. This bar engages a "cam follower" on the end of the piston rod and drives the piston upward, forcing paint through the material line to the gun. The pitch of the inclined bar controls the volumetric rate of paint delivery. Triggering of the gun is controlled from the right handle of the carriage by means of a control cable.

The paint stripe applicator is currently being performance tested, in order to detect and remove any defects before it is placed in service for field testing traffic paints.

Figure 6. Paint Stripe Applicator.

V. PAINT FORMULATIONS

The primary purpose of this phase of the work is to accumulate selected samples of paints of precisely known composition and properties for use in experiments involving the beta backscatter thickness gage, the wear test machine, and the paint stripe applicator. Five types of paints were initially selected for the program. These paints are identified as follows:

1. State of Georgia Specification 41A, Yellow (varnish type)
2. Federal Specification TT-P-115A (alkyd type)
3. Pliolite S-5 type
4. Chlorinated rubber-alkyd type
5. Lacquer type.

This group includes all of the basic types which are in use in large quantities today. These products (with the exception of Georgia 41A) were prepared in one-gallon quantities in a laboratory pebble mill during the summer of 1961.

The following items have since been added to the group:

6. White vinyl toluene/butadiene traffic paint, BX 85-J-98 (Goodyear)
7. White chlorinated rubber-alkyd traffic paint (Hercules Formulation 71).

These items are of interest as candidates for inclusion in a revised Federal Specification for traffic paints.* One-gallon samples of these paints were furnished by Goodyear Tire and Rubber Company and Hercules Powder Company, respectively.

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*Formulations were supplied on the suggestion of Mr. Harold Allen, Chief, Physical Research Division, Bureau of Public Roads.

The most recent additions to the test paint group were two epoxy resin based paints:

8. Epoxy-amine type

9. Epoxy-polyamide type.

The outstanding adhesion and toughness of the epoxy resins justify their inclusion in this group. One-quart batches of these epoxy paints were prepared in a pebble mill.

A major problem observed with many of the laboratory formulated paints was shelf stability. More or less hard settling was observed to occur in paints 2, 3, 4, and 5. In addition, the chlorinated rubber paints, numbers 4 and 7, exhibited a very heavy skin in the top of the can. Insofar as possible, homogeneous specimens of all paints were withdrawn for various tests; however, it now appears to be desirable to reformulate some of these paints to correct these shortcomings.

Paint formulation data sheets for each of the items described above are included in Appendix A.

VI. CONCLUSIONS

1. A thickness gage, utilizing an isotopic source of beta radiation, has been constructed and calibrated for measuring paint film thickness. It is anticipated that this gage will be easily adapted to field tests by the substitution of a portable scaler for the scaler presently in use.

2. A wear test device, simulating very closely the abrasion characteristics of normal tire wear against a paint surface, has been constructed and is being used extensively in studying the wear characteristics of a number of traffic paint formulations.

3. A paint stripe applicator for accurately metering paint flow and applying a stripe of uniform predetermined film thickness has been constructed and is currently being performance tested.

4. Nine paint formulations have been prepared or procured and are currently undergoing laboratory studies.

VII. FUTURE WORK

During the next 12-month period, it is anticipated that the research program will include:

1. Selection of a suitable traffic lane test site and application of test stripes, using the paint stripe applicator.

2. Periodic measurements of loss of film thickness in these field test stripes, utilizing the beta backscatter gage.

3. Continued laboratory testing of paint formulations under varying conditions.

4. Attempts to correlate the field test data with those obtained on the laboratory wear test device.

5. Development of improved traffic paint formulations through use of both laboratory and field test results.

Respectfully submitted:

[redacted]

W. H. Burrows
Project Director

VIII. APPENDIXES

A. Paint Formulations

B. Bibliography

APPENDIX A

PAINT FORMULATION DATA

Project No. B-210

Date May 7, 1962

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 1

Georgia Specification 41A, Yellow

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT	55						
Chrome Yellow	70						
Zinc Oxide	5						
Asbestine	25						
VEHICLE	45						
Synthetic Resin/Tung Oil Varnish	42.8						
Cobalt Drier	2.2						
Petroleum Naphtha	41.3						
Benzene	13.7						

WEIGHT PER GALLON ____________ LBS.

P.V.C. ____________ %

TOTAL SOLIDS:

WEIGHT ____________ %

VOLUME ____________ %

Project No. B-210

Date May 7, 1962

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 2

Federal Specification TT-P-115a, White
(Alkyd type)

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT	50						
Rutile Titanium Dioxide	30		150				
Calcium Carbonate	30		150				
Diatomaccous Silica	20		100				
Magnesium Silicate	20		100				
VEHICLE	50						
Alkyd P650-60%	58.2		291				
CO Naphthenate 6%	0.4		2				
Pb Naphthenate 24%	1.2		6				
Antiskinning agent	0.3		1.6				
VM & P Naphtha	40		200				
			1000.6				

WEIGHT PER GALLON 10.0 LBS.

P.V.C. ______ %

TOTAL SOLIDS:

WEIGHT ______ %

VOLUME ______ %

Project No. B-210

Date May 7, 1962

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 3

Pliolite S5 Type, White

	% WEIGHT	% VOLUME	102 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT	42.7						
Rutile Titanium Dioxide	41		191				
Calcium Carbonate	36.9		172				
Diatomaceous Silica	20.4		95.2				
Aluminum Stearate	1.6		7.6				
VEHICLE	57.3						
Pliolite S5-A	19.2		119				
Chlorinated Paraffin, 55% Cl	19.2		119				
Lecithin	1.2		7.6				
Toluol	24.2		152				
VM & P Naphtha	36.4		227				
			1090.4				

WEIGHT PER GALLON 10.7 LBS.

P.V.C. ______ %

TOTAL SOLIDS:

WEIGHT ______ %

VOLUME ______ %

Project No. B-210

Date May 7, 1962

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 4

Chlorinated Rubber/Alkyd Type, White

	% WEIGHT	% VOLUME	95 GALLON BATCH				
PIGMENT	63		Pounds	Lbs. Per Solid Gal.	Gallons		
Rutile Titanium Dioxide	24.9		208				
Calcium Carbonate	55.1		460				
Diatomaceous Silica	10		83.5				
Magnesium Silicate	10		83.5				
VEHICLE	37						
Chlorinated Rubber (Parlon S-10)	10.2		49.7				
Alkyd P381, 70%	58.7		286				
Toluene	30.1		146				
Propylene Oxide	0.3		1.5				
CO Naphthenate, 6%	0.3		1.5				
Antiskinning Agent	0.3		1.5				
			1321.2				

WEIGHT PER GALLON 13.9 LBS.

P.V.C. _____ %

TOTAL SOLIDS:

WEIGHT _____ %

VOLUME _____ %

Project No. B-210

Date May 7, 1962

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 5

Lacquer Type, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT	40.3						
Rutile Titanium Dioxide	24.9		109				
Calcium Carbonate	55.1		242				
Diatomaceous Silica	10		44				
Magnesium Silicate	10		44				
VEHICLE	59.7						
1/2 Sec NC - 25%	51.2		334				
Amherol 800 - 50%	12.8		83				
Flexol 8 HP	7.7		50				
Lacquer Thinner	28.4		185				
			1091				

WEIGHT PER GALLON 10.9 LBS.

P.V.C. ______ %

TOTAL SOLIDS:

WEIGHT ______ %

VOLUME ______ %

Project No. B-210

Date May 7, 1962

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 6

White Vinyl Toluene/Butadiene Traffic Paint

BX 85-J-98

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT							
Titanox RCHT			296				
Titanox RANC			59				
Fibrene C-400			53				
Celite 261			83				
Mineralite 3X			59				
Bentone 38			5				
VEHICLE							
Pliolite VT-L			107				
Velsicol X-37			35				
Chlorinated Paraffin,40%			35				
Soya Lecithin			8				
Tolusol			357				
			1097				

WEIGHT PER GALLON 11.0 LBS.

P.V.C. 51.5 %

TOTAL SOLIDS:

WEIGHT %

VOLUME %

Project No. B-210

Date May 7, 1962

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 7

White Chlorinated Rubber-Alkyd Traffic Paint

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT							
Titanox RCHT			590				
Asbestine 3X			73				
Keystone Whiting			73				
VEHICLE							
Parlon S-10			45				
65% Soya-PE Alkyd			176				
Soya Lecithin			9.1				
Epiohlorohydrin			1.3				
6% Cobalt Naphthenate			1.3				
Antiskinning Agent			1.3				
Toluene			304				
Mineral Spirits			31				
			1305				

WEIGHT PER GALLON 13.05 LBS.

P.V.C. 55 %

TOTAL SOLIDS:

WEIGHT ______ %

VOLUME ______ %

Project No. B-210

Date May 7, 1962

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 8

Epoxy Amine Type, White

	% WEIGHT	% VOLUME	100 GALLON BATCH				
PIGMENT			Pounds	Lbs. Per Solid Gal.	Gallons		
Rutile Titanium Dioxide			174				
Calcium Carbonate			174				
Diatomaceous Silica			116				
Magnesium Silicate			116				
Bentone 27			6.2				
VEHICLE							
Araldite 571 T-75			253				
Methyl Ethyl Ketone			156				
Toluol			153				
*Beetle 216-8			9.4				
*Diethylene Triamine			11.5				
Butanol			11.5				
			1183.6				

WEIGHT PER GALLON 11.8 LBS.

P.V.C. ______ %

TOTAL SOLIDS:

WEIGHT ______ %

VOLUME ______ %

Project No. B-210

Date May 7, 1962

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 9

Epoxy Polyamide Type, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT							
Rutile Titanium Dioxide			147				
Calcium Carbonate			147				
Diatomaceous Silica			98				
Magnesium Silicate			98				
Bentone 27			5.3				
VEHICLE							
Araldite 502			203				
Toluol			165				
Methyl Ethyl Ketone			165				
*Beetle 216-8			6.6				
*Polyamide 825			87				
			1121.9				

WEIGHT PER GALLON 11.2 LBS.

P.V.C. ______ %

TOTAL SOLIDS:

WEIGHT ______ %

VOLUME ______ %

APPENDIX B

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COVERING THE PERIOD
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ABSTRACT

This report covers technical activities during the second year of project work. Further laboratory and field studies with the beta ray film thickness gage has disclosed the practical capabilities and limitations of this instrument. Paint formulation work with novel vehicle materials has indicated definite potentials for enhanced paint durability. Initial findings of poor correlation of laboratory wear test results with highway tests have led to redesign of equipment and procedures for the laboratory test. The highway tests have provided the basis for evaluating the laboratory tests, and have also yielded valuable field performance information to guide formulation development work on both conventional and novel types of paints.

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I. INTRODUCTION

Original project objectives may be summarized briefly as follows:

1. Development of a highway paint film thickness measuring device based on the use of radioisotopes.

2. Development of laboratory paint wear tests that correlate with field studies.

3. Development of field application equipment.

4. Study of traffic paint formulations.

During the first year of project work the following accomplishments were made:

1. A beta backscatter film thickness gage was constructed and tested in the laboratory.

2. A laboratory wear test machine was constructed and correlation tests were initiated.

3. A field stripe applicator for precise application of lines for test purposes was constructed.

4. A number of traffic paints were formulated for testing.

5. An extensive study of the technical literature pertaining to all phases of the program was completed.

During the second year of project work (the period covered by this report) the following accomplishments were made:

1. More detailed field studies with the beta ray film thickness gage disclosed fundamental measurement difficulties which appear to preclude use of the instrument except for specialized research purposes.

2. Based on laboratory findings a number of "conventional" paints were reformulated for field tests and several paints based on novel vehicles were studied.

3. Development of detailed specifications for catalyzed epoxy type traffic paints was initiated.

4. Extensive testing of the laboratory wear machine disclosed shortcomings in the equipment and precedures. Necessary redesign (incorporation of additional environmental variables) was completed.

5. A carefully planned series of highway cross-stripe tests was conducted, and extensive information was obtained both for correlation with laboratory wear tests and for formulation development.

II. PAINT FILM THICKNESS DETERMINATION

A. Beta Ray Film Thickness Gage

Laboratory work utilizing the beta ray film thickness gage to determine paint film thickness on various substrates was presented in Annual Report No. 1. At that time the similarities in density between white paints and concrete were noted. Subsequently, when field test applications were made the gage was taken into the field and measurements were made on each paint stripe. Figure 1 shows this work in progress. The field tests confirmed the earlier laboratory findings. Readings of counts per minute for Paint No. 6 on concrete and asphalt are shown in Table I. Note that the average counts for paint on concrete shows a maximum difference from bare concrete of only 8.8 or about 2.5 per cent. Even more discouraging is the fact that the range of readings on bare concrete encompasses two out of three of the average readings over paint. Thus, even if the instrument were sufficiently precise to consistently measure 2.5 per cent differences, the variability in the concrete substrate, which is also approximately 2.5 per cent, would entirely obscure meaningful differences. These same difficulties were observed for the readings on the asphalt substrate.

It appears that beta backscatter instrumentation of this type cannot be used effectively to measure thickness of conventional white traffic paints on concrete or asphalt type pavings. Although the performance of the gage with yellow paints was not evaluated on the highway, previous laboratory data together with the field determinations of the concrete and asphalt substrate characteristics would definitely indicate that useful measurements could be made on lead chromate type yellow paints under field conditions. In summary, serious disadvantages of the present gage are:

Figure 1. Night Visibility Tests and Beta Backscatter Thickness Measurements Being Made at Field Site.

TABLE I

BETA GAGE FIELD MEASUREMENTS

		Beta Backscatter, Counts/Min.		
Paint No.	Substrate	Average	Range	Nominal Wet Film Thickness (Mils)
None	Concrete	3313	3278-3366	0
6	Concrete	3395	3363-3436	10
6	Concrete	3352	3303-3389	15
6	Concrete	3342	3339-3345	20
None	Asphalt	3211	3102-3307	0
6	Asphalt	3298	3294-3304	10
6	Asphalt	3296	3217-3343	15
6	Asphalt	3349	3319-3366	20

1. It can only be used on very dense paints.
2. It must be calibrated for each paint and substrate.
3. Individual measurements are slow (1 minute count).
4. Instrumentation is complex and heavy.

B. Paint Inspection Gage

For several years a simple concept in film thickness measurement has been studied on an occasional basis by personnel of the Industrial Products Branch. The original motivation for this study was a recognized need for a device suitable for determining thickness of protective paint systems on structural steel. When a prototype instrument was developed it was natural to inquire into its possible applicability to the highway paint film thickness measurement problem.

A copy of a separate report on the "Paint Inspection Gage" is included in Appendix B. On page 4 of this report, Figure 4 is a reproduction of the measurement of a heavy coat of traffic paint on concrete. The device appears to be inherently capable of producing thickness measurements of good precision. In the special case of highway paints, the microscopic topography of some highway substrates may be too irregular to permit meaningful individual measurements to be made. A final prototype of this gage is now nearing completion, and plans are in effect to evaluate its capabilities for both laboratory and field use in highway paint thickness determination.

III. PAINT FORMULATION WORK

A. Conventional Paints

Formulation details on all paints which have been tested in the laboratory and/or in the field are given in Appendix A. With the exception of Paint No. 1 (Georgia Specification 41 A, Yellow) and Paint No. 28 (Special Alkyd, Yellow) all formulation work was confined to white paints.

The objective of the formulation work on conventional paints was to produce suitable representatives of the following types:

1. State of Georgia Specification 41 A
2. Alkyd (to conform to TT-P-115a)
3. Butadiene/Styrene solution
4. Chlorinated rubber/alkyd
5. Lacquer

In some cases the initial paints produced were not considered to be properly representative. The changes in these formulations are discussed below.

The first alkyd type prepared was Paint No. 2. The laboratory abrasion tests of this paint indicated very poor performance despite the generally good reputation of the alkyds. Accordingly, an alkyd resin of longer oil length was selected and this paint was reformulated as Paint No. 15. Much better results were obtained with the revised formulation.

The butadiene/styrene formulation (Paint No. 3) was obviously too soft and exhibited excessive dirt pickup during laboratory testing. Subsequently, the resin manufacturer submitted a revised formulation based on butadiene/vinyl toluene and this formulation (Paint No. 6) was adopted for further testing.

Storage stability problems were experienced with the chlorinated rubber alkyd (Paint No. 4). After about 6 weeks storage a thick (1/2 inch) film was observed at the surface of the paint in the can. A formulation (Paint No. 7) supplied by the resin manufacturer exhibited the same defect. This item was later reformulated with a different alkyd resin and increased antiskinning agent concentration (Paint No. 16), and after 6 months storage no skinning problem was noted.

The first lacquer formulation (Paint No. 5) was excessively brittle when applied. While it was anticipated that this product should be among the poorest in performance, it was felt that it should more reasonably represent the capabilities of its constituents. Accordingly, this lacquer was reformulated (Paint No. 13) by reducing the total pigmentation, reducing the hard resin, and increasing the plasticizer.

As a result of the foregoing modifications, the set of conventional formulations used for the highway cross-stripe tests and for subsequent laboratory wear testing consists of:

Type	Formulation No.
Ga. Spec. 41 A, White	11
Alkyd	15
Butadiene/Vinyl Toluene	6
Chlorinated Rubber Alkyd	16
Lacquer	13

The Georgia State Highway Department has recently drafted "Tentative Maintenance Specifications" for white and yellow traffic line paints of an alkyd type very similar to Formulation No. 15. "Minimum" (lowest cost) paints based on these specifications have been prepared (Paints 27 and 28) and these items will be tested on the laboratory wear tester.

B. Special Formulations

The testing of novel as well as conventional formulations will be greatly expedited when an accelerated laboratory testing apparatus and procedure have been perfected and evaluated. However, certain relatively new vehicle resins were judged to be of sufficient potential value for use in traffic paints to justify immediate study and testing by such means as were available at the time. Work on these special formulations was carried forward concurrently with the other formulation work. Several selected special formulations were included in the highway cross-stripes applied August 1, 1962. These formulations were evolved approximately as follows.

The first special item studied was an amine-catalyzed epoxy (Paint No. 8). This formulation is based on a hard resin epoxy and exhibits fairly rapid "lacquer drying." Difficulty was experienced in obtaining a satisfactory grind with this formulation and the final paint exhibited an undesirable "puffy" character. This paint was reformulated (Paint No. 14) by modifying the pigmentation in an effort to correct the defect. Only partial success was achieved. When Paint No. 14 was applied in the highway cross-striping tests, it caused stoppages of the spray gun, and after only four stripes were applied it was necessary to abandon further efforts to apply this item.

A potential substantial advantage of epoxies is a capability for formulating with a very high volume of solids by utilizing lower molecular weight liquid epoxy resins which require much less solvent to achieve application consistency. The first effort in this direction was Paint No. 9. This paint was also very difficult to grind and exhibited a "grainy" character. It was thought that the MEK solvent may have been unsuitable and possibly caused some instability. Further, it was known that the co-resin, polyamide, is a superior medium for pigment grinding. Accordingly, this system was reformulated (Paint No. 18) to correct these factors. The stability characteristics of the new formulation were sufficiently improved to permit its use in the field tests. Unfortunately, this type formulation does not dry sufficiently rapidly for practical highway use. The cross-stripes smeared when traffic was released on this paint after about 2 hours drying.

Certain types of polyurethane resins appeared to be of substantial interest as traffic paint vehicles. In particular, a type of resin which cures by reaction with atmospheric moisture looked interesting, especially since it should also be capable of reaction with the concrete or asphalt surfaces to impart specific adhesion with primary chemical bonds. Paint No. 10 was the first preparation of this type. Because of the high reactivity of this resin, even with pigments, it was necessary to slurry-grind the pigments in solvent with addition of a small amount of tolylene diisocyanate. This chemical pre-reacts with functional components of the pigments to reduce their subsequent reactivity with the resin. Because of the relatively large amounts of solvent required for slurry-grinding, the final paint was of a relatively thin consistency. After about one month on the shelf, this paint was gelled in the can, presumably because of residual reactivity of the pigment or solvent. Prior to observing this gelling problem, Paint No. 17 was prepared to correct the initial thin consistency. Approximately one month later when it was to be used on the cross-stripe highway test it was observed to exhibit excessive viscosity. For the field application, this was corrected by thinning with additional solvent. The use of the extra solvent was recognized as an undesirable expedient which would tend to adversely affect the performance of the paint. As the difficulty arises from an insufficient charge of tolylene diisocyanate to inactivate fully the pigment and solvent, further formulation work may correct the gelling difficulties.

C. Practical Epoxy Formulations

This laboratory informed all of the basic manufacturers of epoxy resins of the formulation objectives of this program. Among these manufacturers, Company "A" submitted data on actual use of epoxy resin based formulations by the Illinois State Highway Department in a highway test program for a period of 2 years. A report on this program dated February 27, 1959, was submitted by Company "A" as follows:

"UTSL has developed several traffic paint formulations that have exhibited exceptional adhesion and abrasion resistance qualities. These formulations have been tested by the Illinois State Highway Department on U. S. Route 66 in Springfield, Illinois. As you will note in the table below, the [epoxy formulation] resin-based coatings showed considerably less wear after two years exposure to traffic and weather than did the control, a commercial paint manufactured under Illinois Spec. M6-54.

Strip Number	Formulation	Original Thickness	Paint Remaining After 2 Years
1	[Epoxy formulation] Yellow Traffic Paint	12 mils	75%
2	[Epoxy formulation] Yellow Traffic Paint	8 mils	75%
3 (Control)	Illinois Formulation M-6	16 mils	10%

According to the Illinois State Highway Department, the conventional traffic paint should have been replaced 6 to 8 months before this data was obtained, whereas the [epoxy] resin-based coatings are expected to last 1-2 years more. In other words, the life expectancy of the [epoxy] resin-based traffic paint is at least 2-3 times that of conventional formulations, in spite of the fact that the [epoxy] resin-based paints were applied in much thinner films than the conventional paints. The [epoxy] resin-based coating also exhibited superior glass bead retention."

One gallon of a white epoxy paint and complete formulation data were submitted by Company "A" for testing in the present program. This paint was designated Paint No. 19. Details of the performance of the several epoxy formulations are presented in subsequent sections of this report. It is sufficient to state here that the results of laboratory and highway stripe tests justified additional attention to these items.

Paint No. 19 appeared to represent a fully field practical paint, and a decision was made to develop a set of "Tentative Specifications for Epoxy-Type Traffic Line Paint" based on this formulation. For this purpose, epoxy resins corresponding to those used in Paint No. 19 were obtained from four different suppliers of epoxies. The plan was to prepare the formulation from each set of resins, to test it on the laboratory wear tester, and to qualify all suitable resins for use in the specifications. When the formulations were prepared, all exhibited very unsatisfactory flow characteristics. The consistency might be described as a "heavy whipped cream," and thinning with added solvent did not improve the flow properties. This unexpected result seriously delayed this portion of the program. After much minute checking of materials the source of difficulty was finally isolated; the acetone used in this laboratory was contaminated. The formulation problem was solved when a new supply of acetone was obtained. This experience definitely emphasized the importance of appropriate raw materials specifications. In working with epoxies and other special resins, the standard ASTM specifications for materials may often be inadequate. Accordingly, further investigations of materials specifications are being made to provide assurance that satisfactory paint can be produced by the "Tentative Specifications for Epoxy-Type Traffic Line Paint."

IV. LABORATORY WEAR TESTING

A. Testing and Correlation Work

In Annual Report No. 1 the problem of the gross unevenness of concrete test disc surfaces was discussed. Even the most carefully trowelled surfaces were found to produce erratic wear patterns that tended to obscure significant differences in paint performance. Because of this problem, test work during the past year has been performed almost exclusively on cement-asbestos board surfaces.

For testing purposes a wet film thickness of approximately 15 mils was applied to the test surface by means of a doctor blade. The prepared panels were permitted to air-dry 7 days prior to wear testing. Wear tests were conducted on dry panels and on panels that were maintained continuously wet with water during testing. Test data for Paints 1 through 11 are given in Table II. The condition of paint failure is defined by the earliest observation of a continuous path of exposed substrate for the full length of the wheel track across the specimen.

The results of these tests clearly indicate:

(1) Substantial differences in wear resistance among conventional paints.

(2) Lower wear resistance in the wet condition, except for a single case.

(3) Marked superiority in wear resistance of the special paints.

The degree of correlation between the laboratory wear and the highway cross-stripe tests was of primary interest. Therefore, each of the paints used on the highway tests was also subjected to the laboratory wear test, wet and dry. Results from the highway tests after 7 months exposure are presented, together with the laboratory wear tests, in Table III. The sense of these results is further elucidated by arranging the paints in order of rank (1 - best, 9 - poorest) for the tests as shown in Table IV.

TABLE II

ABRASION TESTS OF VARIOUS PAINTS ON TRANSITE SUBSTRATE

Doctor Blade Clearance: 20 mils

Wet Film Thickness: appr. 15 mils

Paint No.	Description	Cycles to Failure* Dry	Wet
1	Ga. Yellow	+31,200	+32,300
2	Alkyd	67,900	11,600
3	Butadiene/Styrene	+70,000	15,200
4	Chlor. Rubber	+70,000	27,000
5	Lacquer	52,800	+17,000
6	Supplier's Butadiene/Vinyl Toluene	37,900	12,500
7	Supplier's Chlorinated Rubber	47,500	+23,400
8	Epoxy-Amine	+428,000	+27,000
9	Epoxy-Polyamide	+428,000	+27,000
10	Polyurethane	+104,000	+23,000
11	Ga. White	33,000	17,600

*Where a plus sign (+) precedes the value, the test was terminated prior to failure. Generally, this was done in order to preserve other stripes on the same panel as a record of comparative wear. Future tests will be made on panels containing a control stripe, thus permitting more accurate comparison among all of the test paints.

Note that the rank order for dry and wet lab tests are almost identical even though the wet test is more severe. The divergence between rankings of paints on concrete and asphalt highway surfaces is only slightly greater. When lab tests are compared with the highway tests, however, the correlation is seen to be generally poor. The lab tests definitely underrated the alkyd (No. 15), and the

TABLE III

LABORATORY AND HIGHWAY TEST COMPARISONS

Paint No.	Laboratory Wear Results (Count in Thousand Revolutions) Dry Count	Dry Rank	Wet Count	Wet Rank	Highway Wear Results* (7 Months Exposure) Concrete Rating	Concrete Rank	Asphalt Rating	Asphalt Rank
6	35.0	7	12.0	9	2	7	3	7
11	28.0	9	14.5	7	2	6	4	6
13	39.5	5	17.0	5	0	8	2	9
14	77^+	3	52^+	3	-	-	4	5
15	30	8	13	8	5	4	6	3
16	39	6	16	6	8	1	6	1
17	120^+	2	52^+	2	3	5	2	8
18	120^+	1	52^+	1	6	3	5	4
19	77^+	4	43	4	7	2	6	2

*ASTM D713-46 and D821-47.

TABLE IV

PAINT PERFORMANCE RANKINGS

Rank	Paint Numbers: Laboratory Test Dry	Laboratory Test Wet	Highway Test (7 Months) Concrete	Highway Test (7 Months) Asphalt
1	18	18	16	16
2	17	17	19	19
3	14	14	18	15
4	19	19	15	18
5	13	13	17	14
6	16	16	11	11
7	6	11	6	6
8	15	15	13	17
9	11	6	-	13

chlorinated rubber-alkyd (No. 16), and they overrated the lacquer (No. 13). On the other hand, both tests tended to substantiate high performance potentials for the "special" formulations. The urethane (No. 17) and the amine epoxy (No. 14) performed poorly on the highway, but application problems were experienced with these materials, and it was anticipated that their performance would not measure up to their inherent potentials.

Several shortcomings of the laboratory wear tester and procedure were apparent at the time the tests were being run, and the poor correlation with the highway tests became evident within a few months. Accordingly, plans for improving the lab test were initiated several months prior to the present report.

B. Modifications of Wear Test Machine and Procedures

As the highway tests began to mature and the nature of surface wear was observed, the vast differences in the character of the highway surfaces as compared with the laboratory cement-asbestos surfaces was strikingly evident. Even where the highway surface is relatively smooth, paint wear is first observed over exposed aggregate. Thus, the performance of a highway paint may depend largely on its adhesion and wearing qualities on an aggregate substrate. Performance on a cement-asbestos substrate could be very different. It was concluded, therefore, that an improved simulation of the highway substrate may be of critical importance to the laboratory test.

Although trowelled-surface concrete discs had been abandoned as unfeasible because of gross surface variations, it seemed possible that these discs might be used if a uniform surface could be obtained. Some preliminary hand-grinding experiments yielded smooth aggregate-studded surfaces. A decision was made to face a number of the discs by grinding, and to evaluate this type surface thoroughly.

It was evident that some type of machine would be required to grind even a single disc. After considering several possibilities, a simple "stone-mill" was designed as shown in Figure 2. The upper disc turns slowly against the fixed lower disc with sand used as the abrasive between the "stones." Two discs are faced at one time in a period of several hours. Previously tested paints can be removed, and the discs reused by grinding for a shorter time. A photograph of a faced disc is shown in Figure 3. Note the true plane surface under the straight-edge. This new concrete substrate should distinctly improve the laboratory test.

In connection with future laboratory testing another change in procedure has been planned. Where previously a simple, solid 4-inch-wide stripe was applied by a doctor blade to achieve an approximate 15 mil wet thickness, future tests will utilize three 4 inch lines on separate discs at nominal 10, 15, and 20 mil wet film thickness. Furthermore, each line will be applied to overlay a thin strip of cellophane tape which will be removed as the paint dries. This will provide a central base line for precise determination of dry film thickness with a depth micrometer. It will also provide well-defined paint edges for observations of edge-wearing effects. In evaluating a paint, test results will be plotted against the precisely measured original dry-film thicknesses. If desired, single-value comparisons of various paints can then be calculated for a normalized 15 mil wet film thickness. Most important, this procedure eliminates any need for making assumptions regarding effects of film thickness.

Finally, the functioning of the laboratory wear test machine has been critically re-evaluated, and important new features have been incorporated. Briefly, it was decided that the environmental variables of wetting-drying, heating-cooling, and solar irradiation should be included in an accelerated test for highway paints. Modification of the machine to accomplish these objectives is nearing completion.

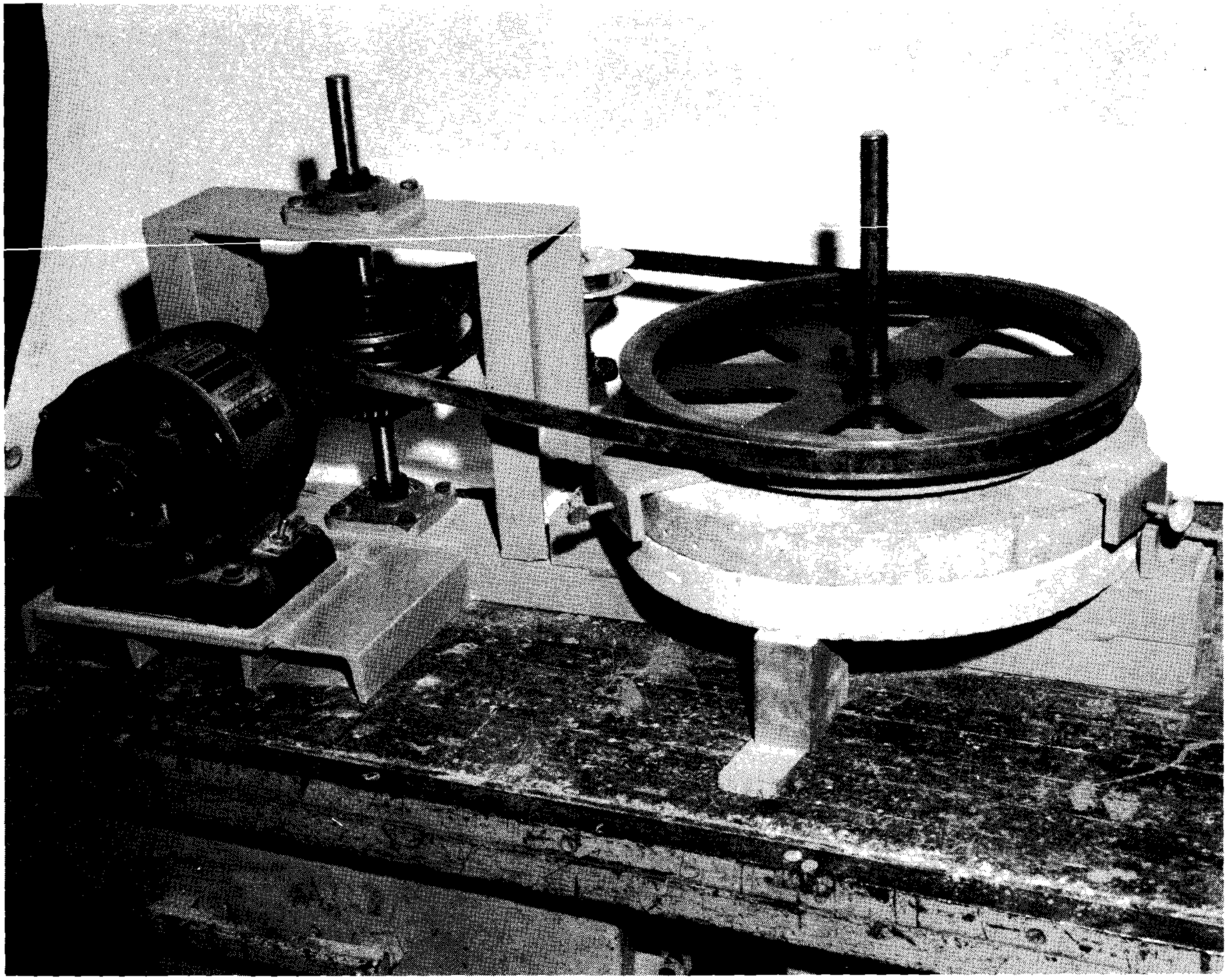

Figure 2. Disc Facing Machine.

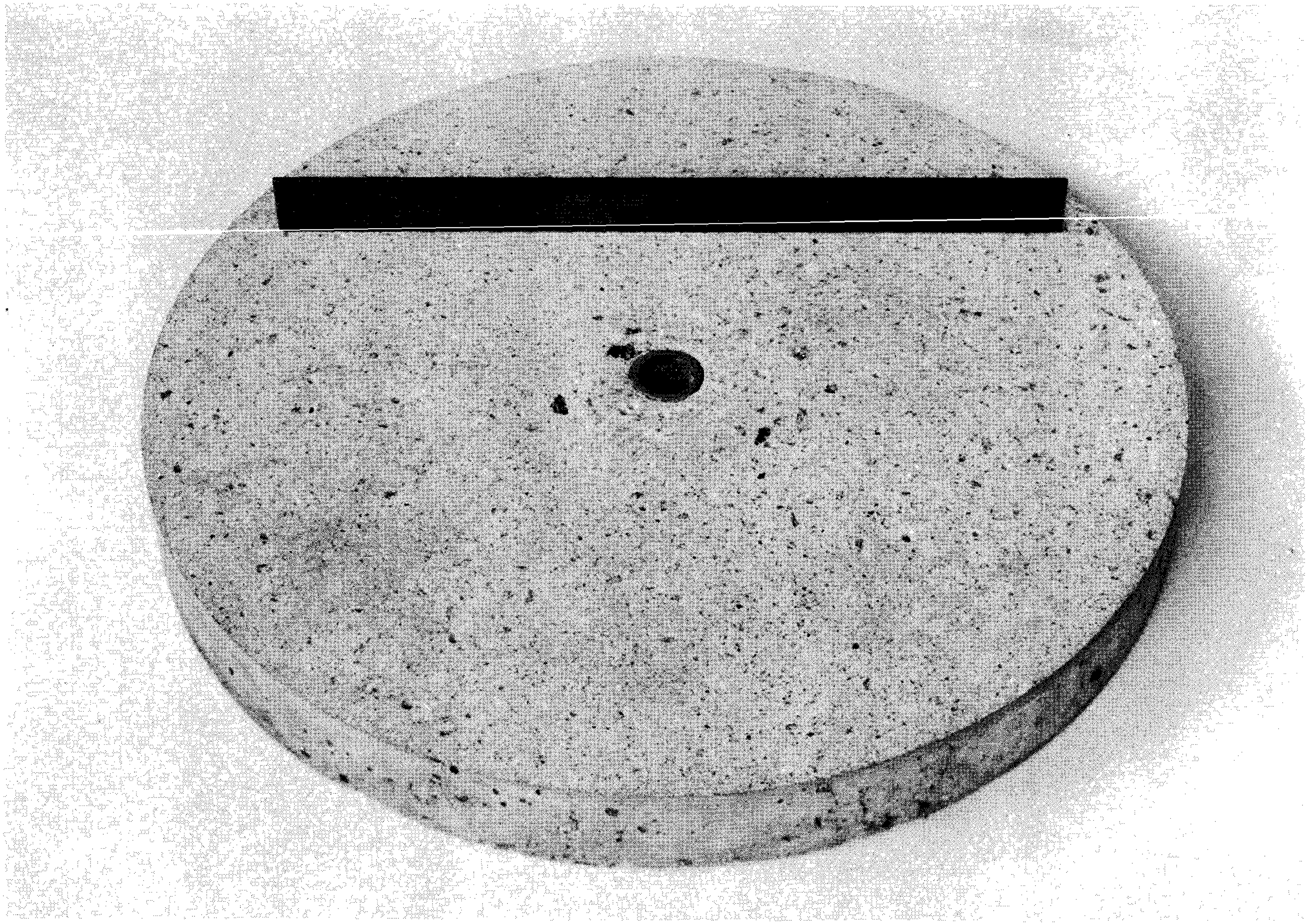

Figure 3. Faced Disc Straight-Edge Shows Trueness of Flat Surface.

V. HIGHWAY CROSS-STRIPE TESTING

A. Site and Plan of Study

The desired location for field tests was one carrying heavy traffic and providing both concrete and asphalt surfaces. Such a site was found on Atlanta's Northeast Expressway (Interstate No. 85) at the bridge over Lenox Road. The traffic count on this artery is approximately 33,000 vehicles per day. The surface is concrete to the south of this bridge; asphalt to the north. The paint tests at this location included nine different paints applied to concrete and asphalt at 10, 15, and 20 mils wet film thickness, with and without reflective beads. This required 12 stripes of each paint for a total of 108 stripes. Because of application difficulties with one paint it was necessary to omit eight stripes; consequently, the applied tests involved exactly 100 stripes.

The nine paints selected for this study included formulations representing all of the basic types of "conventional" highway paints together with several novel types. These tests were designed to determine comparative performance of the various paints for correlation with laboratory wear tests and to evaluate the effects on paint performance of:

(1) Substrate (concrete vs. asphalt)

(2) Paint film thickness

(3) Beading ("bead on" type)

Cross-striping tests were used exclusively in this study rather than longitudinal striping. This decision was based in part on the findings of other investigators* whose extensive studies have demonstrated a very high correlation

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*Shelburne, T. E., Straub, A. L., and Sheppe, R. L., "Field Studies of Traffic Paints," Highway Research Board Bulletin No. 57, 77-90, (1952).

(rank correlation coefficients of 0.88 to 0.98 for durability and reflectance) between transverse and longitudinal tests. Additionally, if longitudinal tests were required, the test section of roadway would become so long that numerous experimental difficulties would be introduced in a program of the scope desired. While the "ultimate" test is the longitudinal stripe, various investigators have concurred that such tests are generally unsuitable for research and development purposes.

B. Paint Preparation, Application and Evaluation Methods

Paint formulation work has been discussed in Section III. For the highway applications, approximately 3/4 gallon of each paint was required. With the exception of Paints No. 6 and 19 which were supplied together with detailed formulation data by raw material vendors, all other paints were prepared in the Industrial Products Branch laboratories in a jar mill.

On August 1, 1962, test Paints No. 6, 11, 13, 14, 15, 16, 17, 18, and 19 were applied transversely to test sites in the outer traffic lane of the Northeast Expressway at the Lenox Road Bridge. Each paint was applied with the paint stripe applicator at wet film thicknesses of 10, 15, and 20 mils, unbeaded and beaded, on concrete to the south of the bridge and on asphalt to the north. Beading was applied at a rate of approximately 6 pounds per gallon of paint using a simple applicator constructed for this purpose. Of the various paints applied, only Paint No. 14 caused equipment difficulties. This amine-catalyzed epoxy paint has previously been observed to exhibit excessive "puffiness" or thixotropy. It caused repeated clogging of the spray gun, and after several lines were applied on the asphalt surface further attempts to apply this material were abandoned. During the application work, primary attention of the operators was directed toward obtaining the specified coating thickness on each line. On the concrete surface, each paint line passed over a strip of aluminum foil attached to the surface to provide a check on applied film thickness.

Application and evaluation of the paints was in accordance with ASTM testing procedures and standards. Applicable methods included:

D713-46	Conducting Road Service Tests on Traffic Paint
D821-47	Abrasion, Erosion Resistance
D913-51	Chipping Resistance
D1011-52	Night Visibility

C. Results and Observations

Observations of film integrity and of night visibility were made at one month intervals. Complete data for 5 months weathering are presented in Table V. Following is a summary of performance results in relation to paint type, film thickness, surface type, and beading.

1. Paint Type

Plots of paint integrity versus time for each experimental paint are presented in Figure 4. Integrity refers to resistance to film failure either by abrasion or chipping in accordance with ASTM D821-47 or D913-51. In most cases failure was by abrasion. Each point on the plot represents the average of the observations at 10, 15, and 20 mils application thickness. Separate plots are presented for beaded and unbeaded paint on concrete and on asphalt.

Plots of night visibility (ASTM D1011-52) versus time for beaded paints are given in Figure 5. It was discovered after the test applications had been made that bead adhesion was secured only in Paint Nos. 15, 16, 17, and 18; therefore, night visibility results are confined to these items. This does not infer that the other paints are necessarily incapable of retaining beads; during

TABLE V

COMPLETE HIGHWAY TEST DATA AT 5 MONTHS

Paint Type	Butadiene/Vinyl Toluene		Ga. Spec.		Lacquer		Amine Epoxy		Straight Aklyd		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
A. Highway Test Film Integrity																		
Concrete																		
10 mils	0	1	2	2	0	0	-	-	3	3	7	8	5	5	6	6	5	7
15 "	4	4	3	4	0	0	-	-	6	6	8	8	3	5	6	6	7	7
20 "	4	5	5	5	1	1	-	-	7	7	8	8	3	5	6	6	7	7
Asphalt																		
10 mils	1	1	3	3	2	2	4	3	6	6	4	4	2	3	5	5	5	4
15 "	4	4	4	4	4	4	4	5	6	6	5	5	2	2	5	4	6	6
20 "	7	7	5	5	4	4	-	-	6	7	6	6	2	2	5	4	7	7
B. Highway Night Visibility Test																		
Concrete																		
10 mils	1	2	2	2	2	2	-	-	3	6	3	7	5	30	4	50	6	7
15 "	2	3	1	2	2	2	-	-	5	23	3	8	4	38	4	9	10	10
20 "	3	3	2	2	2	2	-	-	5	6	3	11	6	47	8	31	10	10
Asphalt																		
10 mils	2	1	1	1	1	1	2	2	3	14	3	3	1	6	5	19	3	3
15 "	3	2	1	1	2	2	2	2	3	15	2	2	2	18	7	5	3	3
20 "	4	4	1	1	2	3	-	-	3	17	2	4	2	19	3	2	3	4

*U = Unbeaded
**B = Beaded

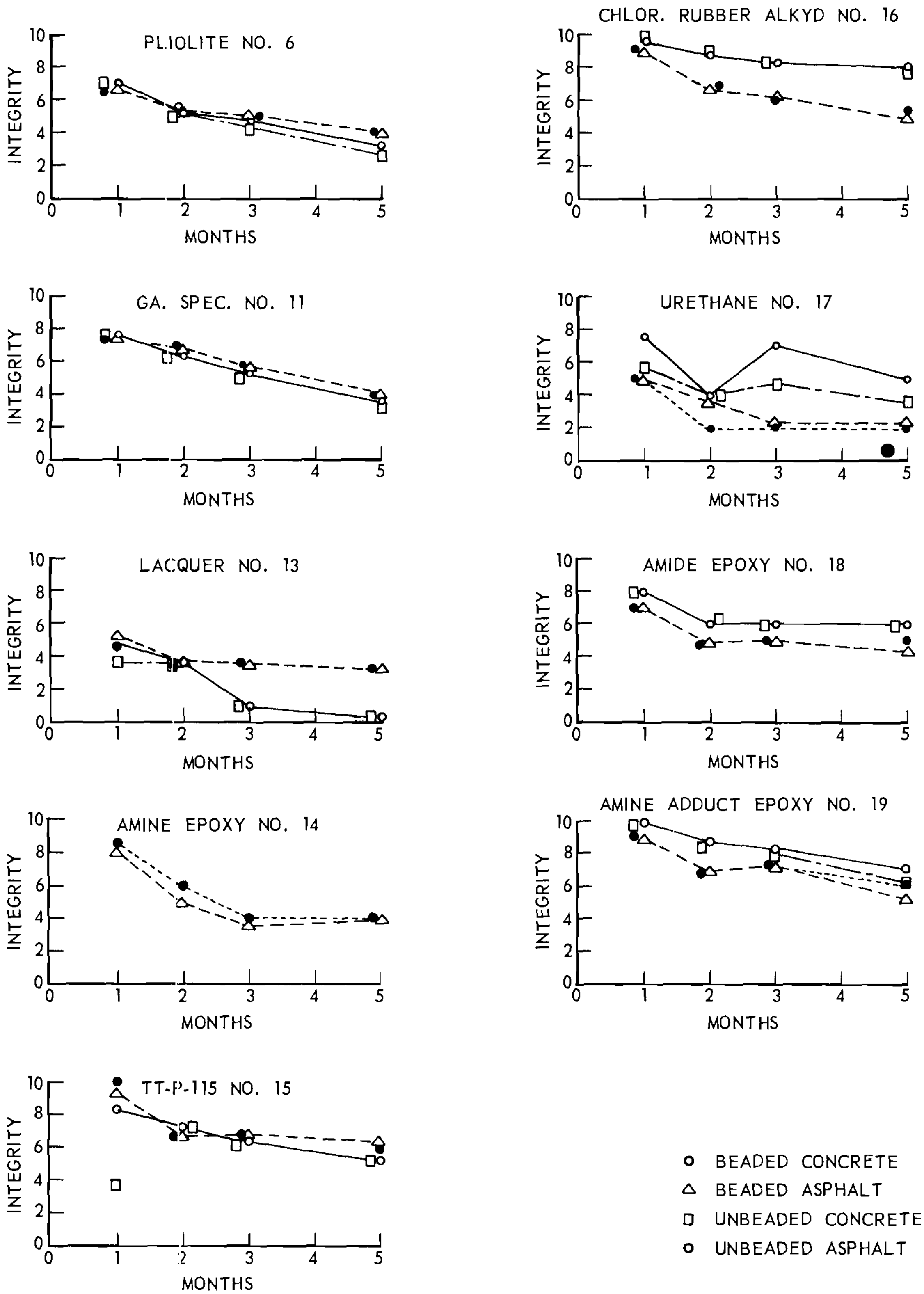

Figure 4. Paint Integrity Versus Exposure Time.

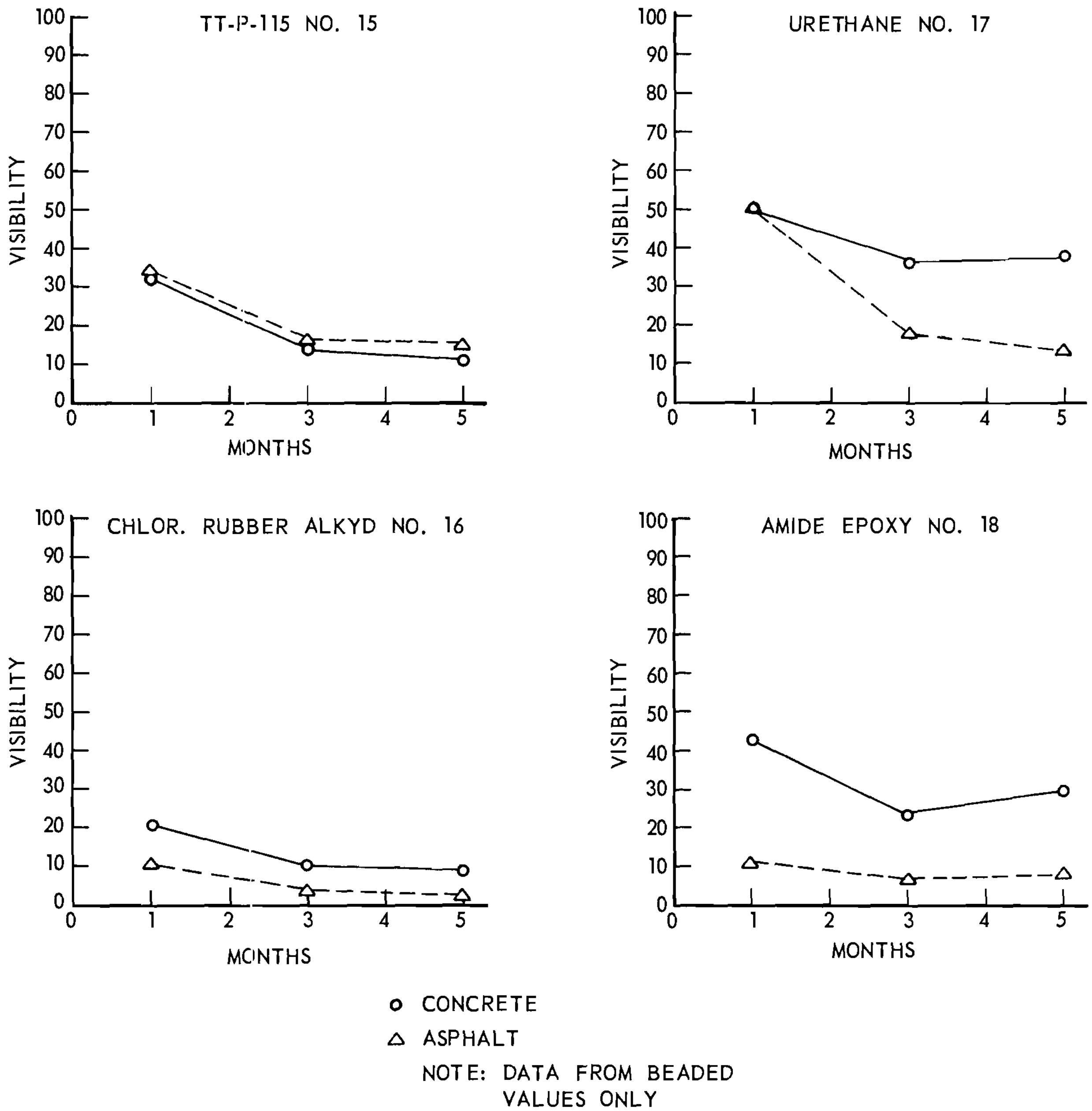

Figure 5. Night Visibility Versus Exposure Time.

the interval between the application of paint and beads, the paint surface may have become too dry for the beads to adhere properly.

The following observations are made concerning the individual paints:

(1) The lacquer type paint (No. 13) is clearly the poorest performer in the group.

(2) The Butadiene/Vinyl Toluene type paint (No. 6) and the Georgia Specification paint (No. 11) exhibited generally similar performance, definitely below the level of the best of the "conventional" formulations.

(3) A straight alkyd (No. 15) and a chlorinated rubber modified alkyd (No. 16) were among the best of the paints tested. Formulation No. 16 gave particularly outstanding integrity performance on concrete. These paints were not equal to some of the "specials," however, in maintaining night visibility.

(4) Application problems were experienced with both the amine epoxy (No. 14) and the polyamide epoxy (No. 18); therefore, comparative judgments should be reserved. It is significant to note that the polyamide epoxy was second only to the urethane paint (No. 17) in retention of night visibility on concrete.

(5) The retention of night visibility on concrete and asphalt by the urethane (No. 17) is particularly noteworthy. This is believed to be the first formulation of this type material ever tested on a highway. While it exhibited a tendency to chip, and was therefore not rated as superior in integrity, its resistance to abrasive wear was clearly outstanding.

(6) The amine adduct epoxy (No. 19) appeared to be the most "practical" of the "special" types for actual field application. It was comparable to the chlorinated rubber alkyd in integrity, but it did not retain beads because of its very rapid drying characteristics.

2. Film Thickness

Examination of average values of integrity at 5 months weathering indicates that even at 20 mils wet film thickness the general trend toward improvement of durability with increasing film thickness does not level off. This trend is shown in Figure 6. Statistically, the differences among the various averages is of doubtful significance. Note, however, that the average values for paints on concrete and for beaded paints both lie above the overall average line.

Night visibility at 5 months versus film thickness for those paints which retained beads is shown in Figure 7. In this case the line for paints on concrete is significantly higher than the overall average, but the trend toward improvement with increasing film thickness is absent. The probable reason for this may be more apparent from the data presented in Figure 8.

Figure 8 is a plot of integrity versus film thickness for the individual paints at 5 months weathering. Note that, with the exception of No. 15, those beaded paints which comprised the data for Figure 4 (Nos. 15, 16, 17, and 18), do not show an upward trend of integrity with increasing film thickness. This observation is consistent with the previously observed superior integrity of these paints. In other words, in the range of film thickness studied, the more durable paints exhibit a relatively constant high level of integrity, and performance does not improve with increasing film thickness. This is, of course, in distinct contrast to the decidedly positive response of the less durable paints to increasing film thickness. The thickness effect may become more evident with longer weathering of the more durable paints.

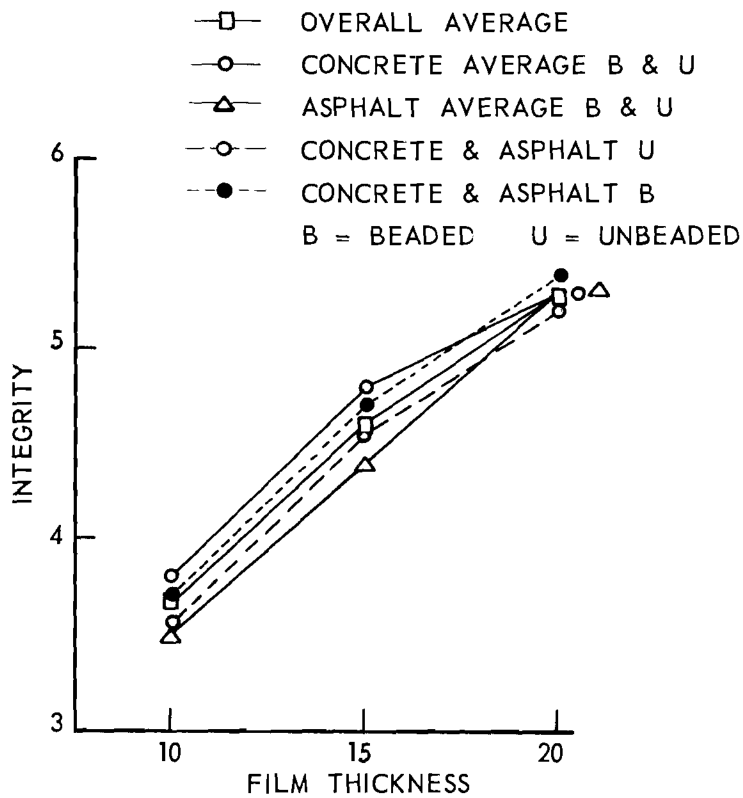

Figure 6. Average Integrity Values Versus Film Thickness at 5 Months Exposure.

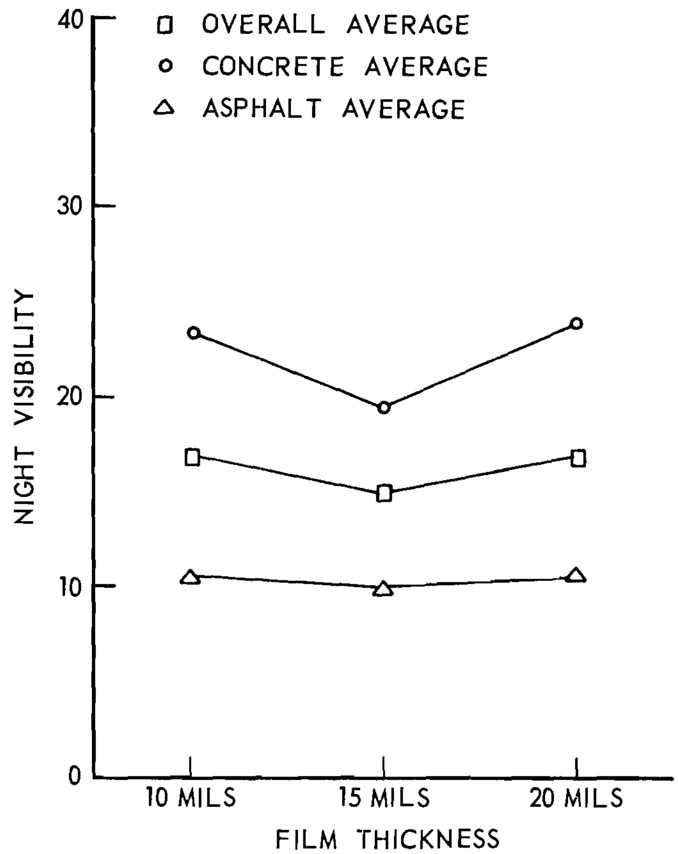

Figure 7. Night Visibility Versus Film Thickness at 5 Month Exposure fcr Paints 15, 16, 17, and 18, Beaded Stripes Only.

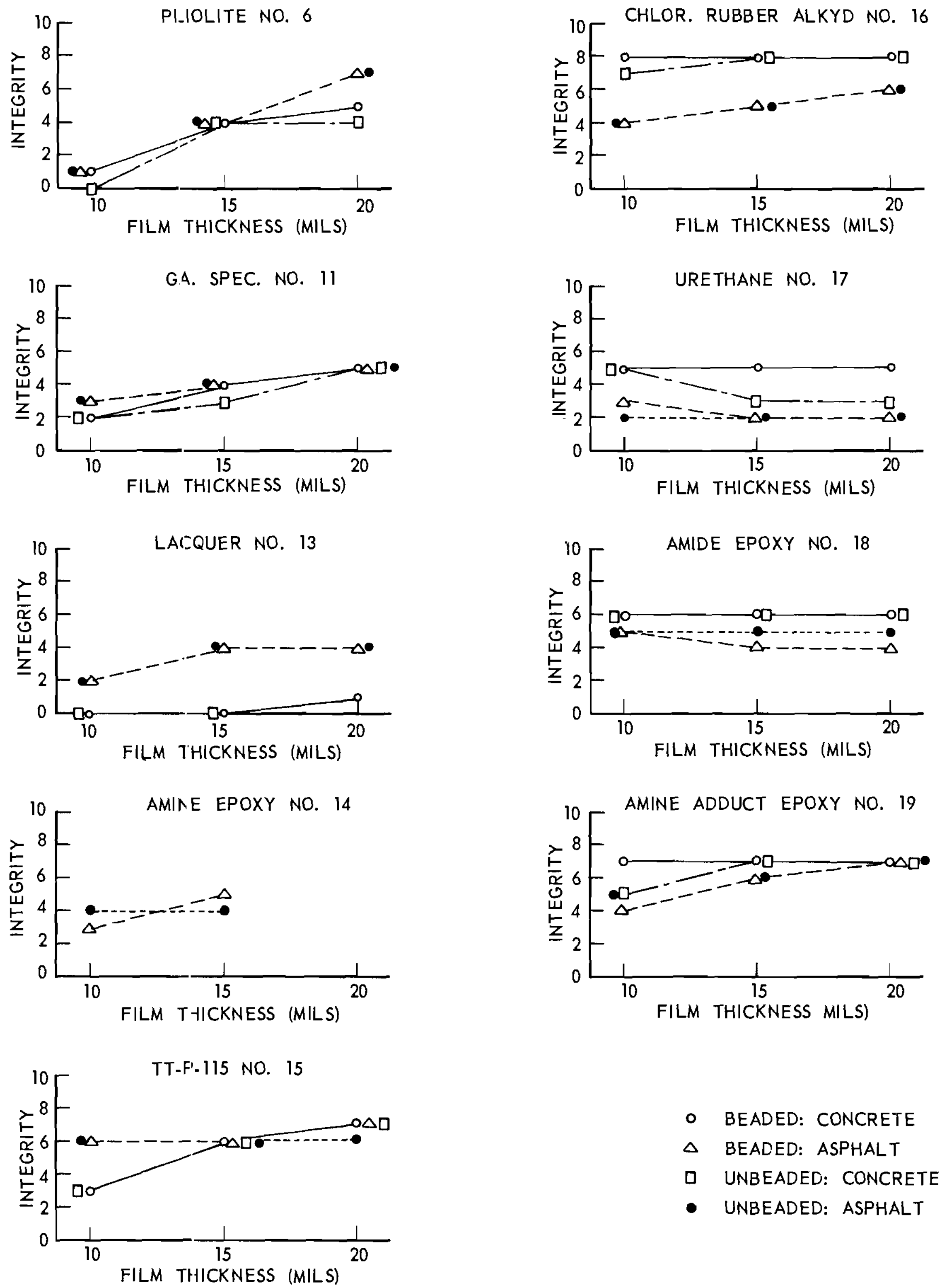

Figure 8. Individual Paint Integrity Value Versus Film Thickness at 5 Months Exposure.

3. Surface Type

The data presented in Figures 4 through 8 clearly show an average superior performance for paints on concrete rather than asphalt. This is definitely not in agreement with historical experience on this subject.* An inspection of Figure 4, however, shows that the "conventional" paints (Nos. 6, 11, 13, 15) do, indeed, follow the classical pattern of better performance on asphalt. It is the "special" paints which have reversed the pattern and weighted the averages. It is assumed that the superior adhesive and cohesive properties of these paints enable them to utilize the more stable characteristics of the concrete substrate. Some of these "special" vehicles may even permeate the concrete surface and serve as a binder or hardener to produce a more stable substrate.

4. Beading

Much of this subject has been covered in the preceding discussions. The following points deserve emphasis:

(1) Superior bead retention, as measured by night visibility, was exhibited by the "special" paints, and particularly by the polyurethane (No. 17).

(2) Bead retention on concrete was superior to that on asphalt, for the limited group studied.

(3) Specific conclusions about bead retention and its effect on durability for most of the paints is not possible, since in most cases it was evident that the beads must have been applied to semidried paint stripes.

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*Goetz, W. H., "Field and Laboratory Investigation of Traffic Paints," <u>Proceedings, Highway Research Board</u> <u>21</u>, 233-259 (1941).

VI. CONCLUSIONS

A summary of conclusions in each subject area of the program is given below:

A. Film Thickness Determination

1. The density of ordinary white traffic paints is too close to the densities of concrete or asphalt highway surfaces to permit successful film thickness determinations with the beta gage.

2. A device based on microscopic examination of a precise groove cut in the paint film appears to be of some value for field thickness determinations.

3. For field cross-striping tests, the application of several stripes of varying controlled thickness appears to be the best present means of evaluating wear rates.

4. For laboratory testing, several changes in procedure have been effected to permit more precise film thickness determination by a micrometer technique.

B. Paint Formulation Work

1. A set of workable representative "conventional" traffic paint formulations of each of the basic types was developed.

2. Several "special" types of formulations involving recently developed resins have been studied and modified, and some appear to be of high potential value.

3. Epoxy-type formulations have been studied in more detail, and work is proceeding on appropriate specifications for an epoxy traffic paint.

C. Laboratory Wear Testing

1. Poor correlation between laboratory and field test results was observed.

2. Various shortcomings in the initial design and testing procedure with the laboratory wear tester were defined.

3. Plans for correcting these shortcomings were developed.

4. At the time of the present report, the construction of the modified machine and auxiliaries was nearing completion.

D. Highway Cross-Stripe Testing

1. Detailed data on performance of a selection of representative paints were obtained for correlation with the laboratory test methods.

2. Guidance towards the development of improved highway paints was derived from these tests.

3. Quantitative information was obtained on the effects of paint film thickness, beading, and pavement type as related to paint performance.

VII. FUTURE WORK

The major effort during the remaining period of the project will be concentrated on a painstaking investigation of the modified laboratory abrasion tester to achieve the closest possible correlation of test results with the highway findings. The improvements that have now been incorporated in this device are believed to provide a very good possibility of realizing the goal of useful correlation.

Paint formulation work will be continued to refine the performance of conventional type paints and to further perfect practical formulations involving the newer vehicle materials.

Respectfully submitted:

W. H. Burrows,
Project Director

VIII. APPENDIXES

APPENDIX A

Paint Formulations

Project No. B-210

Date

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 10

Polyurethane Traffic, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	36.5	14.9				
Rutile 510 - TiO_2	47.5	35.1	228	35.0	6.5	776
Calwhite	31.3	35.7	150	22.6	6.6	511
Celite 281	20.0	27.0	96	19.2	5.0	327
Bentone 27	1.3	2.2	6	14.2	0.4	20
			480		18.5	1634
	100.1	100.0				
VEHICLE	63.5	85.1				
Tolylene Diisocyanate	1.7	1.5	14	8.5	1.6	47.7
Toluene	48.0	52.3	400	7.25	55.2	1362
* Spenkel M86 - 50CX	50.4	46.2	420	8.6	48.8	1430
			834		105.6	2839.7
	100.1	100.0	1314		124.1	4473.7

* Pigments are slurry-ground with T.D.I. prior to incorporation of Spenkel

WEIGHT PER GALLON 10.6 LBS.

P.V.C. 45.8 %

TOTAL SOLIDS:

WEIGHT 52.5 %

VOLUME 32.6 %

Project No. B-210

Date

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 11

Ga. specification 41A, White

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT	55.0						
ZnO	5						
Asbestine	25						
Lithopone	55						
TiO_2	15						
	100						
VEHICLE	45.0						
Synthetic resin	20.2						
Tung oil	22.5						
Conc. (cobalt) Naphtha	2.3						
Petroleum Naphtha	41.3						
Benzol	13.8						
	100.1						

WEIGHT PER GALLON ________ LBS.

P.V.C. ________ %

TOTAL SOLIDS:

WEIGHT ________ %

VOLUME ________ %

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 13

Lacquer type traffic paint, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	25.7	10.4				
Rutile 610 - TiO_2	24.7	17.1	63.0	35.0	1.8	299
Gamaco	54.1	58.1	137.9	22.6	6.1	655
Celite 281	9.8	12.4	25.0	19.2	1.3	120
Nytal 300	10.3	10.5	26.2	23.8	1.1	123
Bentone 27	1.1	1.9	2.8	14.2	0.2	13
	100.0	100.0	254.9		10.5	1210
VEHICLE	74.3	89.6				
1/2 sec N/C - 25%	50.5	47.3	373.2	8.7	42.9	1777
Amberol 800 - 50%	9.3	9.2	69.0	8.3	8.3	328
Flexol 8HP	10.6	10.1	78.2	8.5	9.2	372
Lacquer Thinner*	29.5	33.3	217.9	7.2	30.2	1035
Ethanol 10						
Butanol 5						
Ethyl Acetate 20			738.3		90.7	3512
Butyl Acetate 15						
Toluene 50						
	99.9	99.9	993.1		101.2	4722

300 g thinner used for grinding.

WEIGHT PER GALLON 9.8 LBS.

P.V.C. 47.5 %

TOTAL SOLIDS:

WEIGHT 38.5 %

VOLUME 21.8 %

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 14

Epoxy Amine, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	47.6	22.7				
Rutile 610 - TiO_2	21.6	16.1	150	35.0	4.65	680
Gamaco	32.1	34.1	223	22.6	9.87	1030
Celite 281	10.5	13.2	73.2	19.2	3.81	332
Nytal 300	34.9	35.2	242.5	23.8	10.19	1100
Bentone 27	0.9	1.5	6.0	14.2	.42	27
	100.0	100.1	694.7		28.94	3168
VEHICLE	52.4	77.3				
Araldite 571 - T - 75	42.6	35.5	325	9.3	35.0	1475
Methyl Ethyl Ketone	26.3	30.9	201	6.6	30.5	910
Toluene	25.7	28.0	196	7.25	27.6	890
U F Beetle 216 - 8	1.6	1.4	12	8.6	1.4	54
Butanol	1.9	2.3	14.7	6.5	2.25	67
Diethylene Triamine	1.9	1.8	14.7	8.2	1.80	67
			763.4		98.55	3463
	100.0	99.9	1458.1		127.49	6631

1500g MEK, toluene used for grinding,
Beetle added after grinding,
2.1g catalyst for 100g batch.

WEIGHT PER GALLON 11.4 LBS.

P.V.C. 53.1 %

TOTAL SOLIDS:

WEIGHT 64.8 %

VOLUME 42.6 %

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 15

Straight Alkyd, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	48.0	21.2				
Rutile 610 - TiO_2	29.8	20.8	150	35.0	4.3	680
Gamaco	29.8	32.4	150	22.6	6.7	680
Celite 281	19.8	25.1	100	19.2	5.2	454
Nytal 300	19.8	20.3	100	23.8	4.2	454
Bentone 38	0.8	1.4	4	15.0	0.3	18
	100.0	100.0	504		20.7	2286
VEHICLE	52.0	78.8				
Alkyd P 670-55	69.1	65.8	377	7.5	50.3	1710
VM & P Naphtha	28.2	32.0	154	6.3	24.5	700
Cobalt Naphth. - 6%	0.5	0.5	3.0	8.0	0.4	13.6
Lead Naphth. - 24%	1.4	1.0	7.5	9.6	0.8	34
Mn Naphth. - 6%	0.2	0.3	1.0	8.1	0.2	4.5
Adv. Anti-skin agent	0.6	0.5	3.5	7.8	0.4	15.9
			546.0		76.6	2478.0
	100.0	100.1	1050		97.3	4764.0

200g VM & P used for grinding

WEIGHT PER GALLON 10.8 LBS.

P.V.C. 48.0 %

TOTAL SOLIDS:

WEIGHT 68.1 %

VOLUME 44.3 %

Project No. B-210

Date 6/22/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 16

Parlon Alkyd Traffic Paint, White

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	grams
PIGMENT	60.2	32.6				
Rutile - 610 TiO_2	24.8	17.2	208	35.0	5.9	786
Gamaco	54.8	59.3	460	22.6	20.4	1739
Nital 300	10.0	10.2	83.5	23.6	3.5	316
Celite 281	10.0	12.5	83.5	19.2	4.3	316
Bentone 38	0.5	0.9	4.0	15.0	0.3	15
	100.1	100.1	839.0		34.4	3172
VEHICLE	39.8	67.4				
Parlon S-10 30% in toluene						
Toluene	19.5	21.0	108	7.25	14.9	408
Parlon S-10	8.4	4.8	46.4	13.6	3.4	175
Alkyd P - 296 - 70	51.6	52.3	286	7.7	37.1	1081
Toluene	19.1	20.6	106	7.25	14.6	400
Propylene Oxide	0.5	0.6	3	7.5	0.4	11
Co Naphth. - 6%	0.3	0.3	1.5	8.0	0.2	6
Adv. Anti-skin agent	0.5	0.6	3	7.8	0.4	11
			553.9		71.0	2092
	99.9	100.2	1392.9		105.4	5264

300g toluene for grinding

WEIGHT PER GALLON 13.2 LBS.

P.V.C. 56.7 %

TOTAL SOLIDS:

WEIGHT 77.9 %

VOLUME 57.3 %

Project No. B-210

Date 6/29/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 17

Polyurethane Traffic, White

	% WEIGHT	% VOLUME	100 GALLON BATCH			
PIGMENT	44.3	20.1	Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
R- 610 TiO_2	47.4	35.1	207	35.0	5.92	940
Gamaco	31.4	35.8	137	22.6	6.04	622
Celite 281	19.9	26.9	87	19.2	4.55	395
Bentone 27	1.2	2.2	5.4	14.2	.38	25
			436.4		16.89	1982
	99.9	100.0				
VEHICLE	55.7	79.9				
Tolylene Diisocyanate	2.4	2.2	13	8.5	1.5	59
Toluene	28.1	31.6	154	7.25	21.2	700
*Spenkel M86 - 50CX	69.7	66.2	382	8.6	44.40	1734
			549		67.1	2493
	100.2	100.0	985.4		84.0	4475

700g Toluene used for grinding

*Pigments are slurry-ground with T.D.I. prior to incorporation of Spenkel.

WEIGHT PER GALLON 11.7 LBS.

P.V.C. 45.9 %

TOTAL SOLIDS:

WEIGHT 63.7 %

VOLUME 43.8 %

Project No. B-210

Date 9/29/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 18

Epoxy Polyamide, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch
PIGMENT	53.5	28.6				
Rutile - 610 - TiO_2	29.4	20.5	145	35.0	4.15	659
Gamaco	29.4	31.7	145	22.6	6.42	659
Celite 281	20.1	25.5	99	19.2	5.17	450
Nytal 300	20.1	20.6	99	23.6	4.17	450
Bentone 27	1.1	1.8	5.3	14.2	.37	24
	100.1	100.1	493.3		20.28	2242
VEHICLE	46.5	71.4				
Polyamide 815	24.5	25.5	105	8.1	12.9	477
Toluene	15.4	18.0	66	7.25	9.1	300
Cellosolve Solu.	15.4	17.0	66	7.7	8.6	300
U. F. Beetle 216 - 8	1.6	1.5	6.7	8.6	.78	30
Araldite 502	43.2	38.1	185	9.56	19.3	840
			428.7		50.68	1947
	100.1	100.1	922.0		70.96	4189g.

600g thinner used for grinding,
Beetle added after grinding.
30.5g catalyst for 100g of batch.

WEIGHT PER GALLON 13.0 LBS.

P.V.C. 39.0 %

TOTAL SOLIDS:

WEIGHT 85.4 %

VOLUME 74.7 %

Project No. B-210

Date 7/2/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 19

EPON resin formulation XYA-200
white traffic paint
(Supplied by Shell Chemical Co.)

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	52.5	25.0				
RCHTX - TiO_2	60.9	57.7	386	26.9	14.3	1752
Asbestine 3X	38.8	41.5	246	23.9	10.3	1117
Al. Stearate #909	0.3	0.8	2	10.0	0.2	9
			634		24.8	2878
	100.0	100.0				
VEHICLE	47.5	75.0				
EPON 1001-A-80	20.8	17.4	119	9.3	12.93	540
EPON 1007-CT-55	30.2	27.7	173	8.4	20.57	785
Acetone	33.2	38.9	190	6.6	28.9	863
Toluene	12.2	13.0	70	7.25	9.6	318
Beetle 216-8	1.7	1.5	10	8.5	1.1	45.4
Curing Agent U	1.9	1.8	11	8.5	1.3	50
			573		74.4	2601.4
	100.0	100.3	1207		99.2	5479.4

WEIGHT PER GALLON 12.2 LBS.

P.V.C. ________ %

TOTAL SOLIDS:

WEIGHT 68.8 %

VOLUME ________ %

Project No. R-210

Date

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 20 to 29

	% WEIGHT	% VOLUME	GALLON BATCH				
PIGMENT			Pounds	Lbs. Per Solid Gal.	Gallons		
VEHICLE							

(This series of formulations was prepared during the second year of project work; however, since no testing of these items was completed and reported, detailed formulation data is being deferred for inclusion in a subsequent report.)

WEIGHT PER GALLON ______ LBS.

P.V.C. ______ %

TOTAL SOLIDS:

WEIGHT ______ %

VOLUME ______ %

APPENDIX B

Paint Inspection Gage

A PAINT INSPECTION GAGE

by

W. R. Tooke, Jr.*

Current specifications for protective painting frequently include not only the number of coats of paint to be applied, but also the minimum required film thickness of each coat and of the total paint film.(1) Proper observance of such specifications is distinctly helpful in assuring optimum paint performance. Unfortunately, the field painting inspector has seldom been properly equipped to cope with this type of specification. Moreover, in many practical situations in the field, none of the previously available film gages have been capable of providing the required measurements. The unique ability to observe and measure individual coats of paint in multicoat films on any type of substrate is the outstanding feature of this new instrument.

Inspection Gage Described

The Paint Inspection Gage is, in effect, a major refinement of the sharp penknife. Despite the availability of a number of non-destructive type film gages, the penknife has continued to be the principal tool of astute painting inspectors and of paint technologists for evaluating the physical qualities of field-applied films.(2) Figure 1 is a photograph of the Paint Inspection Gage. In the Paint Inspection Gage, the penknife has been replaced by a precisely shaped hardened steel cutting tool. The tool is shaped to produce a V-cut in the paint film of exactly 45 degrees angle to the surface. Two short guide studs on the body of the instrument form a tripod with the cutting

* Special Research Engineer, Georgia Tech Engineering Experiment Station

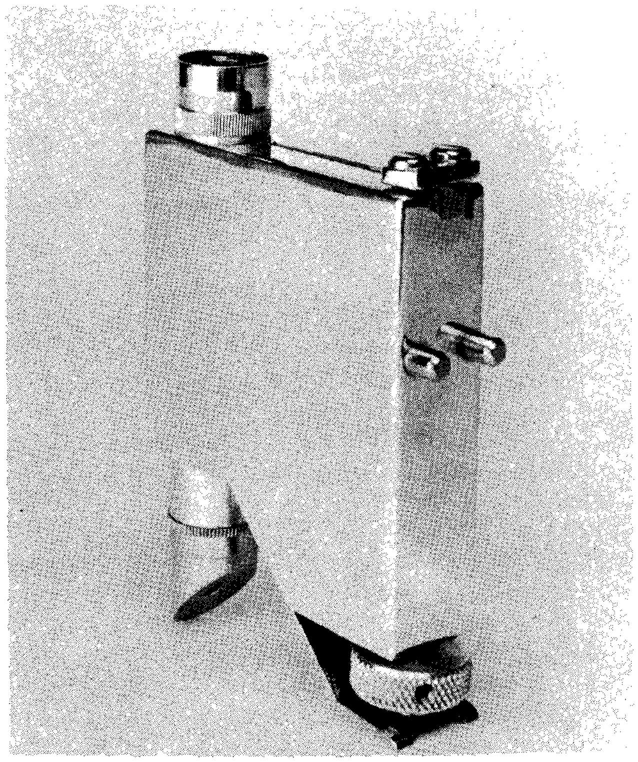

Figure 1. Paint Inspection Gage.

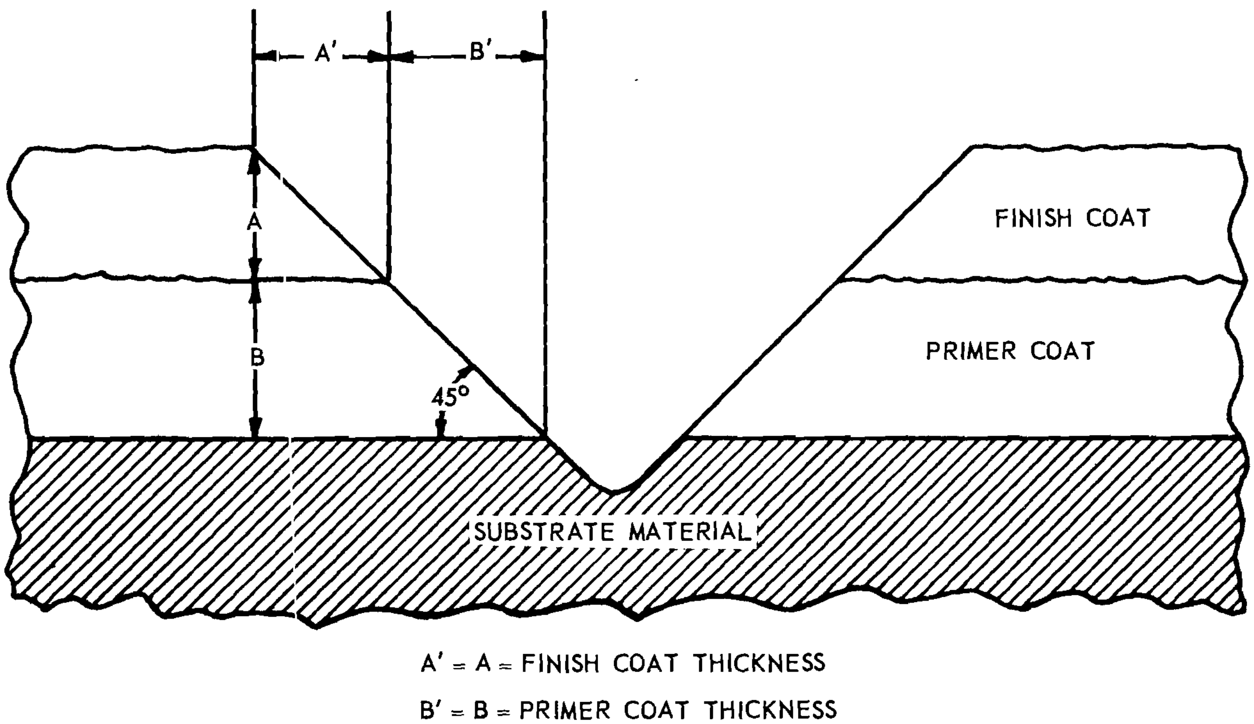

Figure 2. Measurement Principle of the Film Inspection Gage.

tip to provide proper alignment with the painted surface to be examined. A short stroke with moderate pressure scribes a precise narrow 45 degree channel down to the substrate. This channel is then examined with the small 50 power illuminated microscope which is integrally mounted on the instrument. The microscope contains a calibrated reticle with graduations of one mil. Since the projected width of the cut in the paint is identical with the depth, a direct measurement can be made of total film thickness and even of individual coats so long as sufficient color or texture contrast exists. A cross-section diagram of the V-groove is shown in Figure 2.

Advantages and Limitations

Film thickness on any type of substrate can be determined with the Paint Inspection Gage without the necessity for careful calibration. Before scribing the paint film, it is usually helpful to make a small mark on the painted surface with a contrasting color using a brush pen or grease pencil. The scribe is then made at right angles to the mark. As shown in the following microscopic views, this technique greatly facilitates measurement of the film thickness of the top coat by clearly defining the interface of the top coat with the overlying mark. Figure 3 is a view of a three coat paint film on steel as examined through the microscope. Note the smooth appearance of the left wall of the cut and the roughness of the right wall. All measurements are made on the left wall because the cutting tip is designed to provide a sharp slicing action on that side. One heavy coat of traffic paint on concrete is shown in Figure 4, and three coats on wood appear in Figure 5. The ability to examine and measure films on any type of substrate is the most important advantage of the gage.

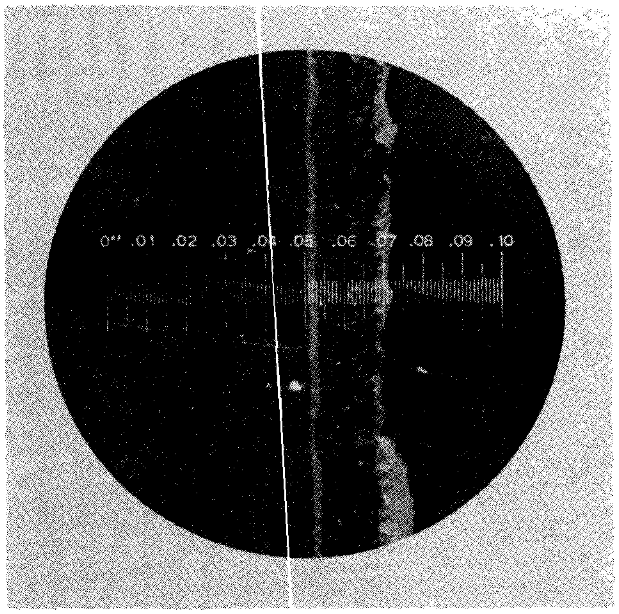

Figure 3. Three Coat Paint Film on Steel.

Figure 4. One Heavy Coat of Traffic Paint on Concrete.

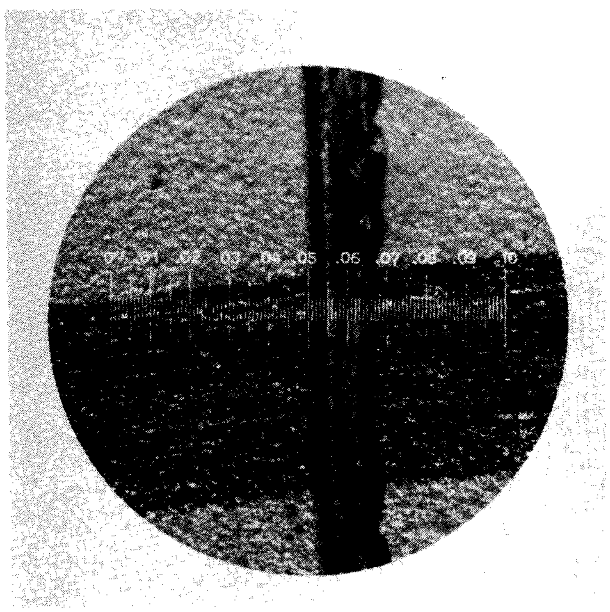

Figure 5. Three Coat Paint Film on Wood.

All structural steel contains a blue-grey oxide surface coating of mill scale of varying thickness. Except in specifications requiring sand-blasting or pickling of the steel, paints are applied directly to the mill-scaled steel. This presents no problem for the Paint Inspection Gage, but for the various types of non-destructive gages, calibration for the varying thicknesses of the mill scale is virtually impossible. Similarly, in repainting work, other types of gages are unable to determine the difference between new and old paint.

Certain definite limitations of the new gage should be recognized. Some rubberlike materials, formulations containing asbestos fibers, and brittle coatings may not yield clean cuts with the tool. Under these conditions, measurements of thickness are at best estimates. A few types of coatings are so tough as to completely resist cutting with the tool. Where extremely thin films are applied as in some product finishes, and where a completely non-destructive measurement is mandatory, this gage is obviously inapplicable for film thickness measurement. Even in many of these cases however, the Paint Inspection Gage may serve other purposes as well as film thickness determination.

Evaluation of Film Properties

The microscope alone is a very valuable tool for critically examining a paint film. An idea of the resolving power of the 50X microscope may be gained from the view of an 80 line halftone shown in Figure 6. This microscope is ideal for observing very fine cracks and checks, floating and flooding, cratering, and other fine surface defects. Figures 7 and 8 show a red paint before and after exterior exposure. Note the cracking of the

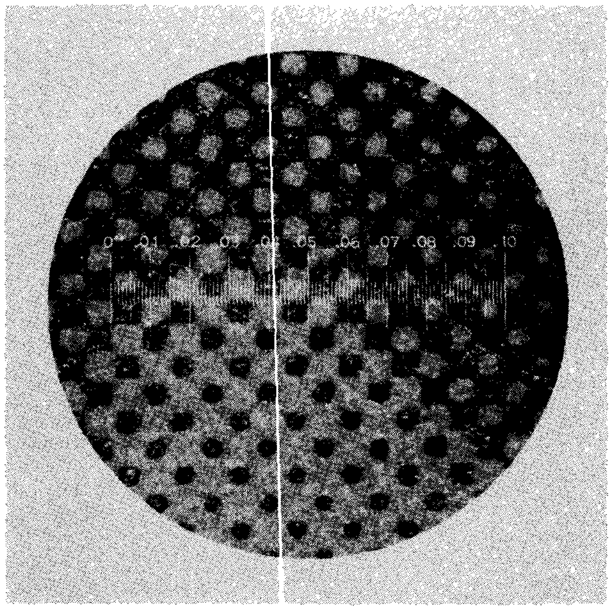

Figure 6. View of an Eighty Line Halftone.

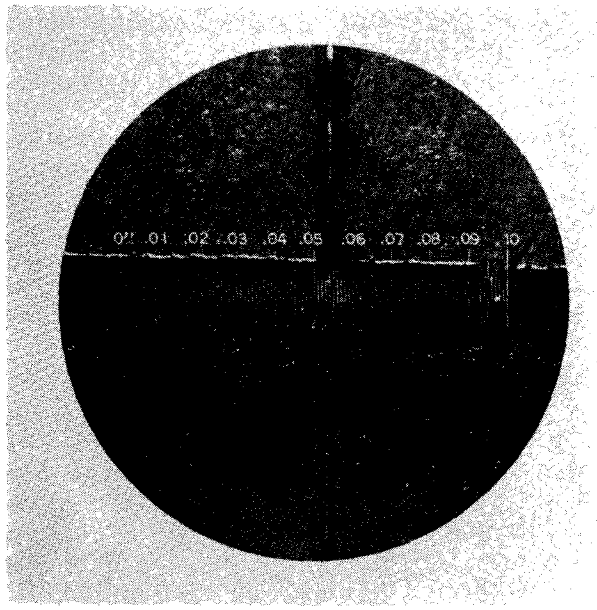

Figure 7. Red Paint Before Exterior Exposure.

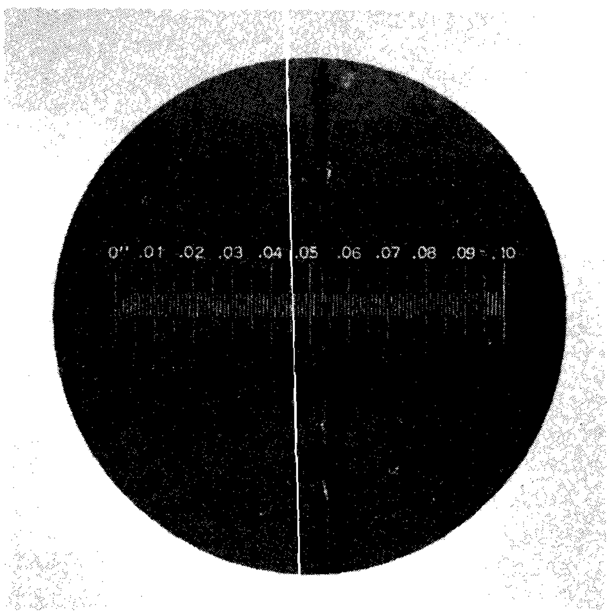

Figure 8. Red Paint After Exterior Exposure.

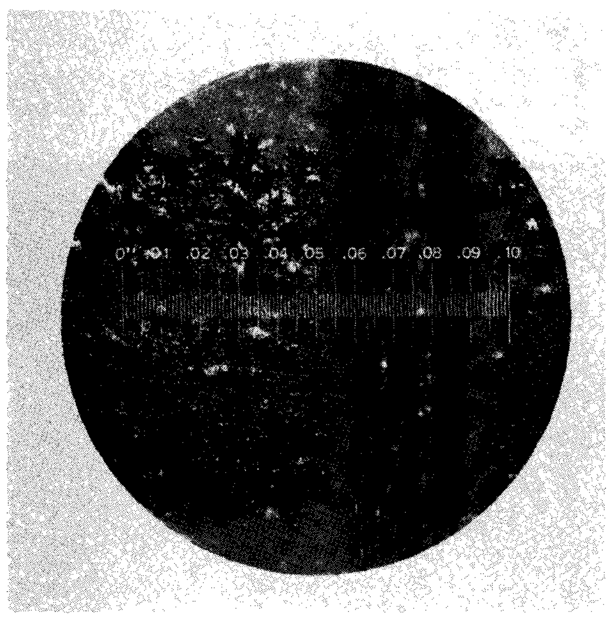

Figure 9. Brittle Paint Film on Wood.

weathered film. These cracks are not visible to the naked eye. In addition to observing the foregoing phenomenon, it is most instructive to observe the character of the cut produced by the tool. Good sound paint films produce a fairly smooth, clean cut with a trace of roughness in the slice. Permanently "plastic" materials such as asphalt yield a very smooth cut without any trace of roughness in the sliced area. When films are brittle or have become embrittled with age, they tend to produce jagged edges in the cut. Figure 9 shows such a brittle paint film on wood. Frequently the substrate is exposed beneath the "sawtooth" effect demonstrating a lack of adhesion. An excellent judgment of the actual condition of an aged paint film may be afforded from a simple examination of the cut.

Precision of Measurements

As a direct-measuring instrument, the Paint Inspection Gage is not subject to the calibration errors that at times render other types of gages completely useless. The reticle scale rests on a fixed shoulder within the microscope barrel. Each microscope is checked for accuracy during manufacture. The maximum allowed scale variation from a primary machine-ruled grating standard is $\pm$ 0.5%. The average error is less than $\pm$ 0.5%. Since the smallest scale division is one mil, measurements may be easily estimated to the nearest one-half mil. A maximum error of $\pm 1^\circ$ is allowed in the grinding of the cutter tip. Microscopic examination of the cross section of cuts in various types of paints indicate that the cut corresponds almost identically (well within 1°) with the angle of the cutting tip. Occasionally some distortion will be observed near the top surface of the film and some smearing of paint at the substrate interface. These effects can be identified and compensated during film inspection with the Gage microscope. Where an angular error of $\pm 1^{\circ}$ occurs in a paint film 5 mils thick, the corresponding thickness error would be approximately $\pm$ 0.17 mils or $\pm$ 3.4%. In this case the percentage error remains the same regardless of film thickness.

The angular positioning of the microscope barrel by the observer during observation yields the same type of error as caused by variations in cut angle. A bipod front-support on the instrument is provided to assure orientation of the microscope barrel perpendicular to the surface.

Visual accuity is not a significant factor as long as the observer's vision is correctable. The microscope may be focused to adapt to the observer's eye. The precise definition of interfaces between coating layers can sometimes present some difficulties. This is evident, of course, in some of the photomicrographs.

There is no way to quantitatively estimate the effects of blunder-type errors. Notice should be given, however, to the fact that the reticle scale markings represent in themselves a perceptible width. When very thin films are being measured the observer should adopt a convention of measuring from the left or right edge of the lines.

From the foregoing discussion, it will be seen that the controlling factor in measurement precision is the ability of the observer to estimate distances of less than one mil. Repeated observations by several observers indicate that the maximum error is approximately $\pm$ 0.25 mils. Accordingly, the expected precision of measurements would vary from $\pm$ 25% at one mil to $\pm$ 2.5% at 10 mils.

Conclusions

The Paint Inspection Gage is a new tool for paint film evaluation. Its value to the field painting inspector for yielding indisputable facts will be obvious to anyone who has ever been involved in this essential and sometimes controversial task. Of almost equal importance is the application of this gage to the problems of the paint technologist. In the laboratory, the response of paint films to this test may quickly provide information of much value to the paint formulator. In the field, however, the diagnostic value of the Paint Inspection Gage may be expected to gain for it the status of a primary tool of the paint inspector.

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2. Federal Test Method Standard No. 141, Method 6304, General Services Administration, Washington 25, D.C., (1958).

SPECIAL REPORT

LABORATORY STUDIES OF NOVEL RETROREFLECTIVE TRAFFIC PAINT GRANULES

PROJECT NO. B-210

by

W. R. Tooke, Jr.

Prepared for

Georgia State Highway Department
Atlanta, Georgia

November 5, 1964

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I. INTRODUCTION

Visibility, and more specifically, wet night visibility, is one of the most important characteristics needed in effective traffic delineation materials. A recent proposal request issued by the Highway Research Board (Project 5-5) for fundamental studies on this subject serves to underline the acute importance of wet night visibility. The dangerous inadequacy of conventional traffic paints is evident to any driver in nighttime and inclement weather. The availability of mechanical types of wet-visible markers does not appreciably reduce the need for a wet-visible paint.

The present study is addressed solely to the problem of enhancing the retroreflective qualities of a traffic paint under wet conditions. It was first necessary to define the problem in terms of the physical principles involved. On a wet road, beaded traffic stripes are usually completely covered with a film of water which totally quenches the retroreflectance of the beads. The quenching occurs because at the grazing angle of incidence of automobile headlamps on the road surface, the water film reflects very nearly 100% of the light in a forward direction and this light never reaches the beads.[1] Therefore, the only possibilities for achieving wet visibility by retroflection are:

1. To keep the beads dry.
2. To eliminate the grazing angle of incidence.

The first approach was discarded as unfeasible, although methods for enhancing the water repellance of paint films may deserve some consideration.

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[1] F. W. Sears, Principles of Physics, p. 28, Addison Wesley Press, Ire, New York, (1948).

Thus, the reduction of the angle of incidence of headlamps on the wet surface appeared to be the only practical approach.

This objective could be achieved by including some sort of granular material on or in the paint film that would be of sufficient size to protrude above the water film and thus present a face more nearly perpendicular to the incident light. A suitable granular material might be simply a graded crushed stone of appropriate size. Further consideration, however, suggested the following requisite properties for an "ideal" material:

1. Present maximum face area at a sufficiently high angle from the horizontal to shed water film.

2. Present adequate flat area toward painted surface to promote bonding.

3. Exhibit three-dimensional symmetry so that orientation of the granule is unnecessary.

4. Possess retroreflective (beaded) surfaces to maximize brightness.

On the basis of these properties, a tetrahedron was selected as the most nearly ideal shape. A decision was made to undertake a laboratory evaluation of the wet night visibility of granules of this shape when distributed on a painted surface in comparison with a regular beaded traffic stripe.

It is emphasized that this research investigation was concerned only with the demonstration of a principle of wet night visibility which might be practical in service applications. Various developmental problems have been considered but have not been studied experimentally.

II. PREPARATION OF GRANULES

The composition of the granules was of very secondary interest for the present experiments; however, laboratory personnel were familiar with slip-casting ceramic techniques. Ceramic granules would also exhibit the durability required if developmental work should be undertaken subsequently. Accordingly, a master mold was machined from a plate of acrylic plastic to provide a pattern of multiple small tetrahedrons approximately 1/4 inch on each side. Several plastic impressions were taken from the master for the slip casting operations. A conventional whiteware body was used with firing to cone 2 (about 2050° F).

Some difficulties were experienced in attempting to deposit glass beads on the granules. The method used successfully involved dropping granules prewetted with an acrylic resin adhesive[2] into a continuously rotating vessel charged with a quantity of dry beads. After coating, the beads were removed and the adhesive allowed to thoroughly air dry. At best, the uniformity of beading was only fair, and there remains a large potential for improvement in this operation. The beading of the granules was intended only to be adequate for the qualitative observations of wet night visibility. A quantity of about three pounds of beaded granules was prepared.

III. RETROREFLECTIVE PERFORMANCE TESTS

A. Laboratory Apparatus

The experimental demonstration was limited to a bench scale because the granules could not be produced economically in the laboratory in sufficient quantity for a full scale study, and also because the bench study permitted more precise definition and control of optical and geometrical variables.

[2] Acryloid A21 LV, Rohm and Haas Company.

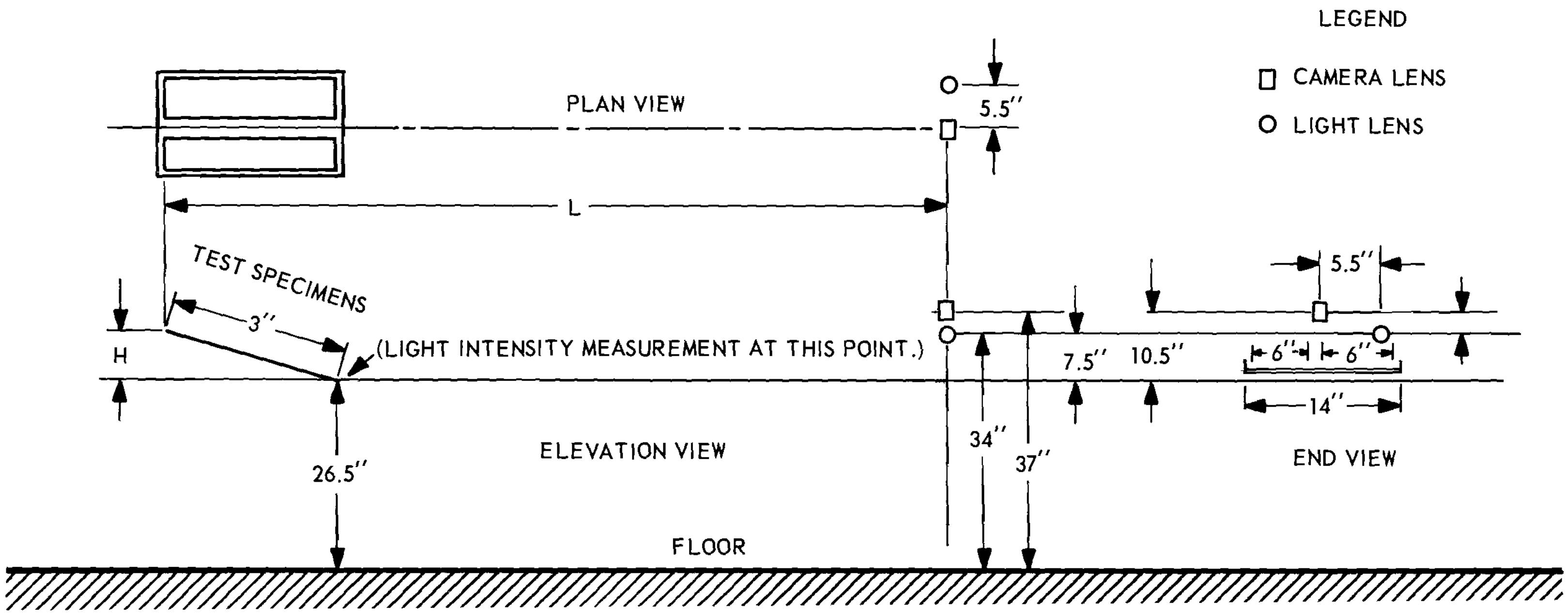
For a scaled-down experiment, a range of 30 feet appeared necessary to gain even a fair approximation of highway geometrical conditions.

A diagram of the test setup is shown in Figure 1. A dark hall in the basement of the Hinman Research Building was utilized for these experiments. The holder for a pair of test specimens consisted of a shallow rectangular pan with leveling screws at each corner. The pan was mounted on a table and enclosed with a large hood to eliminate stray light effects. All of the surfaces of this assembly were painted flat black to minimize unwanted reflections. Two stations for the light-camera assembly were utilized at distances of 10 and 30 feet from the specimens. The camera was a Linhof 4 x 5 with 150 mm lens and photographs were made utilizing Kodak Royal Pan film. The light source was a Bardwell and McAllister Kleig light with a 750 watt lamp and a Foco-Spot attachment.

Because of their size, it was not possible to position the camera and the light source sufficiently close together to attain exact similitude with driver-highway-headlight geometry. Computations of angles of incidence and divergence indicated that these deviations would not affect the validity of the comparisons required in this experiment. Accordingly, the camera and light source were positioned as closely as their dimensions permitted. As an approximation, the 10 foot test range corresponds to about 25 to 100 feet on the highway, and the 30 foot test range corresponds to about 100 to 275 feet on the highway. The computed values are for left and right headlamps respectively.

B. Specimen Preparation, Tests and Results

Sheet steel panels 6" x 36" were used as a base for specimen preparation.



PHOTOGRAPHIC SETUP

PHOTO NO.	L(FT.)	H (IN.)	SPECIMEN CONDITION	LIGHT INTENSITY (FT.-CND.)
1	30	0.5	DRY	7
2	10	0.5	DRY	120
3	30	0.5	ONE HALF IMMERSED 0-1/4″	7
4	10	0.5	ONE HALF IMMERSED 0-1/4″	120
5	30	0.0	FULLY IMMERSED 1/8″	7
6	10	0.0	FULLY IMMERSED 1/8″	120

Figure 1. Schematic of Night Visibility Test Range.

A control specimen was prepared by spray application of 15 mils wet of conventional alkyd traffic paint with drop-on beading at a rate of six pounds per gallon. The test specimen was prepared similarly with the beading excluded, and with test tetrahedron granules dropped on by hand at a density of approximately 1200 granules/ft^2. These panels were prepared several weeks prior to the photographic tests.

The test apparatus was assembled, and the panels were mounted flat in the shallow pan holder with the beaded control on the right and the granule test on the left as observed by the camera. The first set of photographs were made at 10 and 30 feet with the panels completely dry and with the rear end of the pan elevated 1/2 inch from the horizontal. A second set was made with the rear of the pan similarly elevated 1/2 inch and with water introduced at the front of the pan so as to immerse each panel for one-half of its length. A final set was made with the pan leveled and with water adjusted to a depth of approximately 1/8 inch above the bare top face of the panels. Under this condition the beaded panel was fully covered with a continuous thin film of water. The test conditions are summarized in Figure 1 and the corresponding photographs are shown in Figures 2, 3 and 4.

IV. DISCUSSION AND CONCLUSIONS

Under dry conditions (Figure 2) the smooth beaded paint film exhibits somewhat higher reflectance than the experimental granular surface; however, this difference may be negligible from a functional viewpoint. Under wet conditions the great superiority of the granular surface is illustrated (Figure 4) by the virtual disappearance of the beaded paint. The total

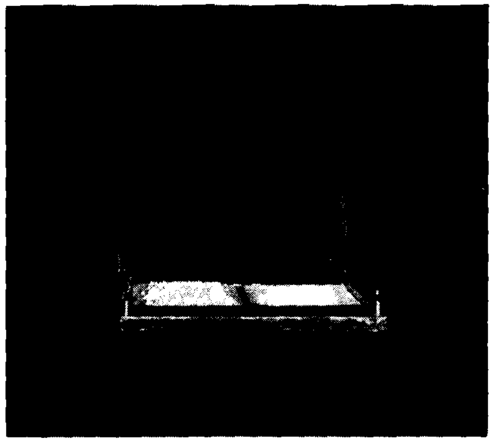


PHOTO NO. 1
RANGE: 30 FEET

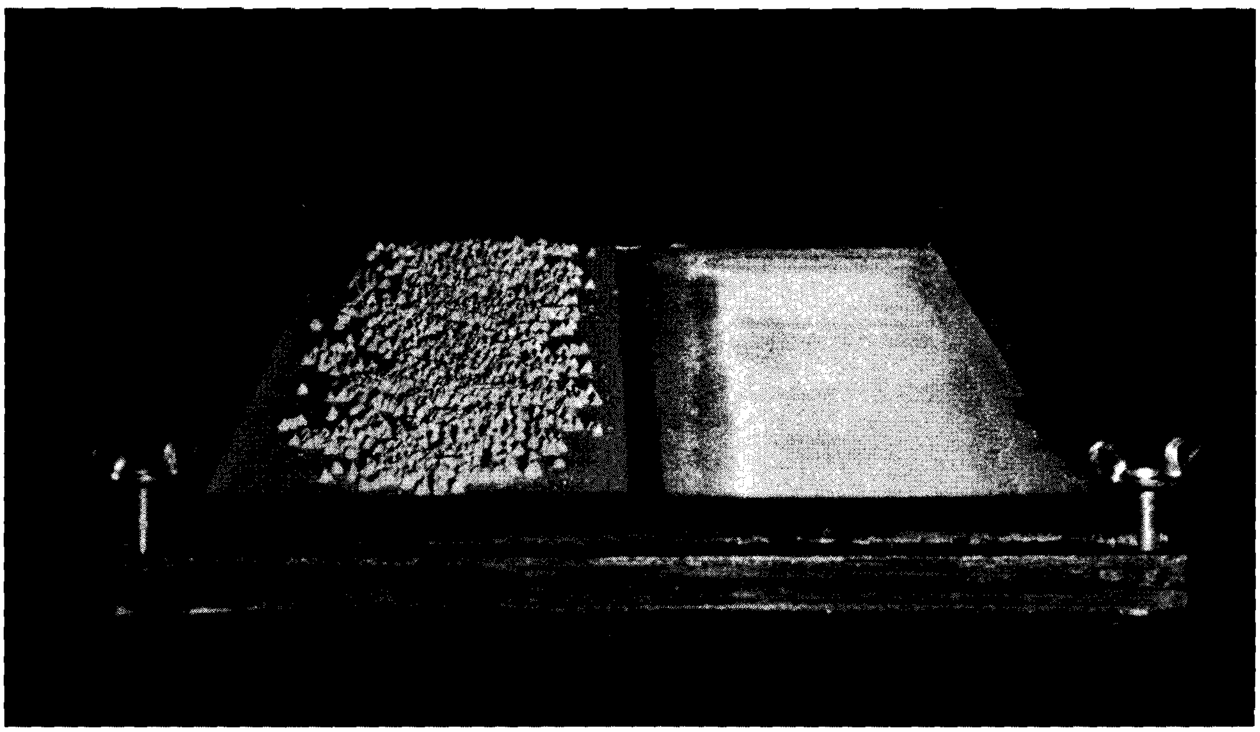


PHOTO NO. 2
RANGE: 10 FEET

Figure 2. Completely Dry Test Panels.

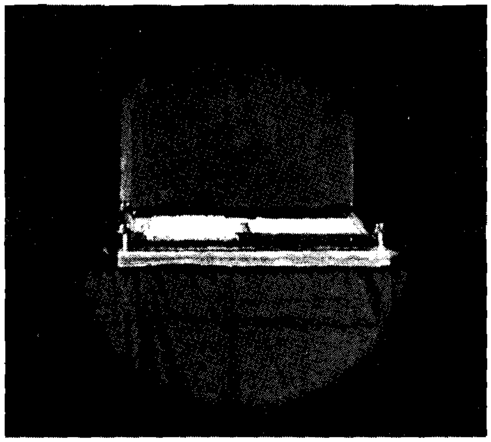


PHOTO NO. 3
RANGE: 30 FEET

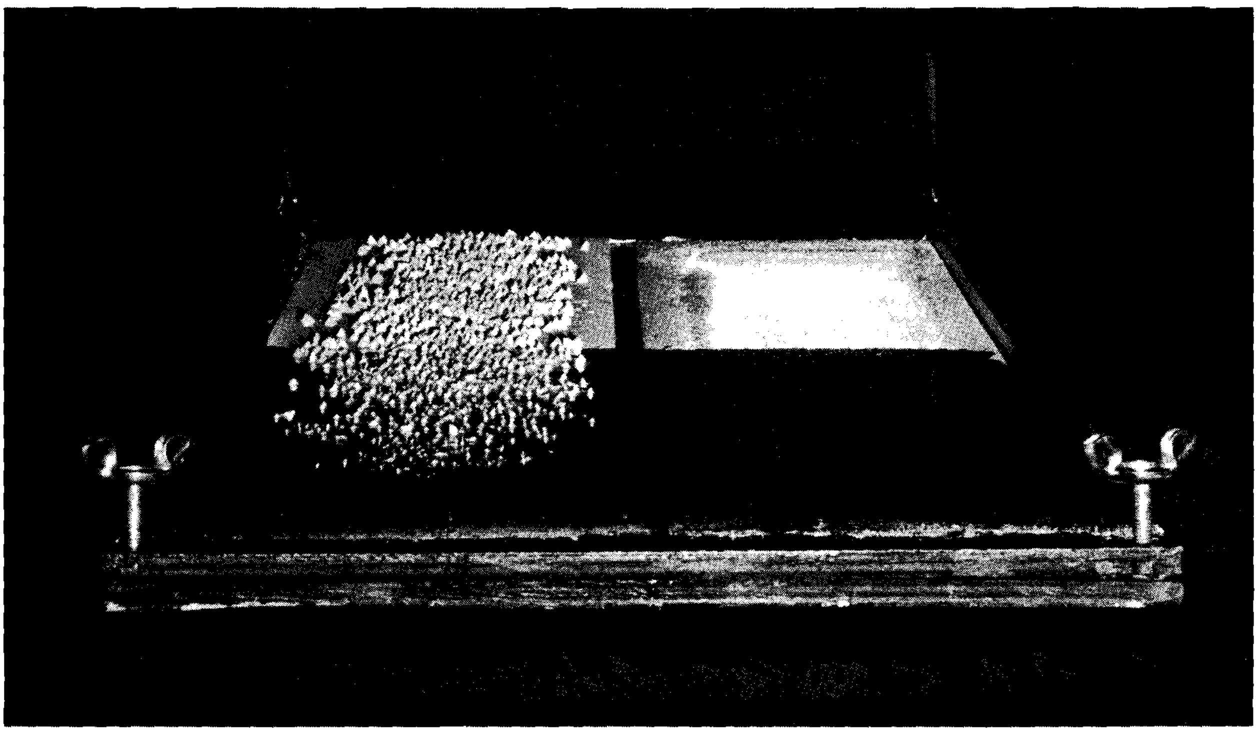


PHOTO NO. 4
RANGE: 10 FEET

Figure 3. Half Immersed Test Panels.

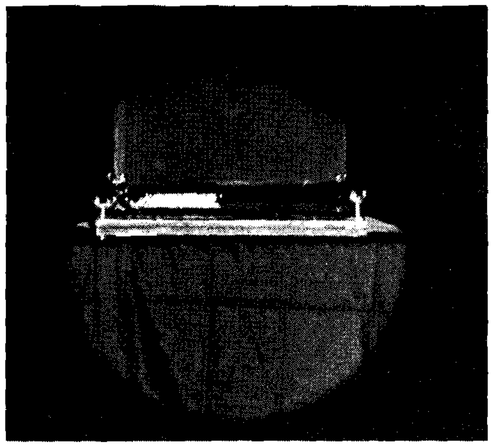


PHOTO NO. 5
RANGE: 30 FEET

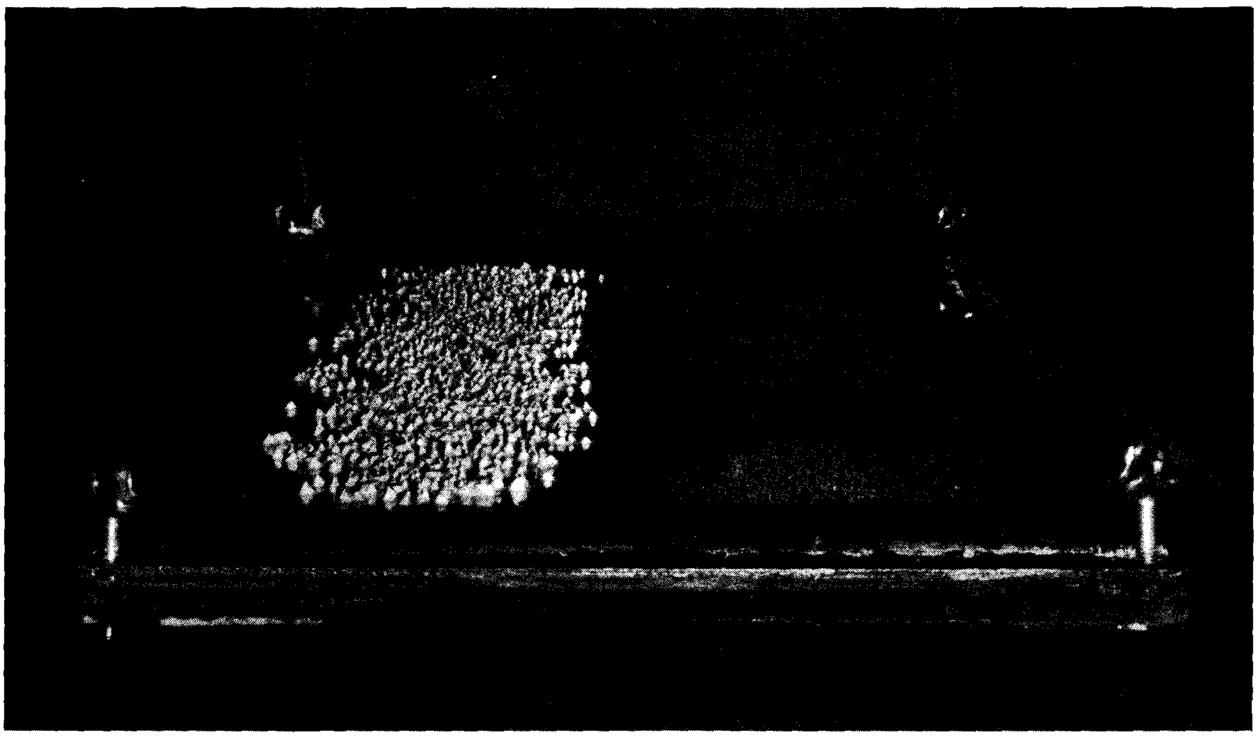


PHOTO NO. 6
RANGE: 10 FEET

Figure 4. Fully Immersed Test Panels.

masking effect of water on the beaded paint even in a very thin film as compared with an almost negligible dimming effect on the granular surface (Figure 3) further illustrates the important differences in the reflectance properties of these surfaces. It is also important to note that as the water depth increases toward the front of the panel as shown in Figure 3, granules are still visible almost to the front edge of the panel. Consequently, it appears probable that smaller size granules may be capable of providing adequate wet night visibility enhancement. Accordingly, some latitude is indicated in the choice of granule sizes to meet the various special requirements for highway service use.

On the basis of the foregoing observations, it is concluded that the experimental granular treatment of traffic paint films produces a sufficient enhancement of the retroreflective qualities of the wetted surface to justify further developmental work and field testing of this principle.

V. RECOMMENDATIONS

1. Subject to the findings of a patent novelty search, it is recommended that appropriate patent applications be filed to protect the interests of the State of Georgia and the Federal Government in this development.

2. In order to complete the developmental aspects of this work, it is recommended that a separate project on this subject should be established. Present funding of Project No. B-210 cannot provide for continuation of this work.

VI. APPENDIX

PROPOSED OUTLINE FOR FURTHER STUDIES OF GRANULAR MATERIALS

The following outline is presented generally in the order that the developmental phases would be pursued. It will be recognized that in such developmental work, the earliest possible attack of the ultimate problem can yield a feedback of needs to the supporting phases to achieve improved economy of effort. These observed needs would guide the distribution and sequencing of activities among the several phases of the work.

A. Preparation and Properties of Granules

The initial work in this area would seek to determine if an irregular shaped granule such as crushed stone would be a candidate for this application. If this approach appears promising, further attention may be directed toward development of suitable specifications and treatments. In any case, it is anticipated that a crushed stone may be selected to serve as a "model" material for use in other phases of the work pending the development of quantities of more suitable granules.

Various types of granules and surface treatments would be investigated, but, subject to contrary findings it will be assumed that a durable beaded tetrahedron-shaped granule is needed for the project and would be developed.

B. Laboratory Studies of Application and Performance

Exploratory studies of suitable paints or adhesives for bonding granules to concrete and asphalt surfaces would be undertaken. The laboratory wear tester would be used to evaluate both the bonding materials and the granule durability. As soon as workable techniques have been evolved, these findings would be applied to preliminary field application and performance studies.

Laboratory studies would then be continued to contribute further improvement of materials and methods.

C. Field Application Problems

Initial highway applications would be undertaken on a relatively small scale and be directed more toward the practical demonstration of the principle rather than the economical development of the method for use. When these applications have displayed sufficient merit, attention would be directed toward necessary equipment development for full scale use.

D. Field Performance Studies

As indicated above, this phase of the work would begin at the earliest possible moment, continuing throughout the entire work period. The final objective of these studies would be to demonstrate an economical means of achieving wet night visibility with a paint-type line marking system.

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia

FINAL TECHNICAL REPORT

Georgia Tech Project B-210

Research Project HPS-1(60)

USE OF RADIOISOTOPES IN DEVELOPMENT OF TEST METHODS AND FORMULATIONS FOR TRAFFIC PAINTS

By

W. R. TOOKE, JR. and W. H. BURROWS

PART I

HIGHWAY CROSS-STRIPE TESTS OF TRAFFIC PAINTS SERIES I

SEPTEMBER 30, 1965

Prepared for
STATE HIGHWAY DEPARTMENT OF GEORGIA

in cooperation with
U. S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

FOREWORD

One has only to travel a short stretch of newly paved and, as yet, unmarked multilane roadway to appreciate the value of traffic markings. Their contribution to the safety of vehicle and pedestrian, their enhancement of traffic flow, and the aid they lend to other traffic control devices makes them an indispensible feature of today's streets and highways.

The earliest traffic marking materials were merely conventional paints and lacquers, not particularly well adapted to this new purpose. With increasing need for lane and crosswalk delineation, edge marking, cross-over control striping, etc., a demand was created for marking materials which would eliminate the shortcomings of conventional coatings materials. This demand has been met only to a limited degree, for present conventional traffic paints still suffer from limited durability, inconvenient drying time, and visibility limitations, especially that of nighttime-wet weather visibility. Although great improvements have been made, the economic and safety value of further improvements can be very large.

Alternate marking materials have been developed and are in use; these include metal and ceramic buttons, plastic tiles, hot melt compositions, and inlay, to mention a few. Each has application to certain special areas of traffic delineation. But, since cost is probably the major factor involved, paints remain the traffic marking materials of greatest volume use and most general applicability, a position which they will probably maintain. New materials and techniques are constantly being added to the resources of the paint formulator, and there will continue to be an increasing need for study and improvement in the formulation and testing of traffic paints.

Such was the prime purpose of this project. At the time of its inception, there was much interest in the possibilities of recently developed techniques employing radioisotopes. One application in particular seemed worthy of investigation; the use of atomic radiation as a means of measuring the thickness of a highway paint stripe. Of somewhat less interest was the possibility of using a radiation detecting method as a guidance device on traffic marking machinery. These ideas were incorporated, along with the prime purpose of the project, in a set of four objectives, as follows:

1. Development of a device, utilizing radioisotopes, for the purpose of measuring the dry film thickness of highway paints, both in the laboratory and in the field.

2. Development of laboratory wear tests that can be correlated with the actual wear of traffic paints in highway use.

3. Development of special highway paint application equipment utilizing radioisotopes. This equipment will control the thickness of application and position the fresh stripe directly over the existing stripe.

4. Formulation of traffic paints, utilizing the devices and findings of the foregoing studies, to improve the performance of traffic paints.

Objective 1 was concluded early in the course of the project. A backscatter thickness gage was constructed utilizing beta radiation from a Cesium-137 source, and based upon a similar instrument designed and constructed by B. W. Pocock of the Research Laboratory, Michigan State Highway Department. A full description of this instrument and its evaluation is given in Quarterly Progress Report No. 3, dated February 7, 1962, a portion of which is included in the supplement of this report.

A severe limitation to the use of this instrument was the lack of discrimination between portland cement concrete and white traffic paint. Inasmuch as backscatter of beta radiation is a function of the density of the material upon which the radiation impinges, the nearly identical densities of the concrete and the paint made it impossible to read film thickness with any desirable degree of accuracy. There was somewhat better discrimination between white paint and asphalt concrete, although even in this case, the density of the concrete aggregate was sufficient to limit accuracy severely. Yellow paints, based upon lead chromate pigments, have higher densities and yielded more satisfactory thickness readings; however, a device could not be accepted for one system and rejected for another. Moreover, individual calibration would be required for every paint-substrate system. In view of these limitations, further use and development of the radiation backscatter technique for thickness measurement was abandoned.

It was obvious from this evaluation of the radiation technique that application to highway paint application equipment would fail; consequently, the third objective was never undertaken. Not only did the radiation fail to provide the necessary discrimination, it also required a reading time of several minutes for each measurement and was far from providing the instantaneous results needed for automation of application equipment.

Objective 2, the development of a laboratory wear test machine and suitable accelerated testing procedures, has been pursued with more rewarding results. Revisions and modifications have been made during the course of the project, with the result that a substantial contribution has been made toward a better understanding of the capabilities and limitations of laboratory wear testing methods. This phase of the project is described in full in Part III of this report.

Objective 4 was pursued during the full course of the project. Although formulation work was not undertaken in a comprehensive manner, the advantages and shortcomings of various novel vehicle materials were evaluated, and at least one candidate vehicle for an improved traffic paint was developed. The continuing laboratory developmental work provided materials for the wear test machine and for highway field tests. The latter were conducted in three series, the first of which was completed in twelve months, with a final inspection at 18 months; this series is described in Part I of this report. Series II and Series III of the highway exposure tests are reported in Part II.

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I. INTRODUCTION

This investigation constitutes one series of studies in a broad research program on traffic paint formulations and testing methods extending over the period 1961-65. This first series of highway tests was concerned with the development of data for correlation with laboratory wear tests, and with the effects upon paint integrity and night visibility of the parameters of paint formulation, film thickness, substrate and beading. The series was conducted in groups of transverse stripes painted across a full traffic lane on a heavily traveled section of Interstate 85 near the city limits of Atlanta, Georgia. In the course of the investigation, formulations, methods of application and methods of evaluation were critically examined and improvements were made in each area of the work.

Transverse test stripes have been utilized for some years to evaluate traffic paint performance; Hickson[1] reports such tests in use by the Bureau of Standards as early as 1927. Wear variations on a transverse stripe correspond to the frequency of tire tread contacts and graphically illustrate the wearing effects of traffic density from curb to centerline.[1, 2] For good quality paints, the wear rate may vary by a factor of three from centerline to track area. The distinct acceleration of wear rate thus provided is a prime reason for choosing transverse striping over longitudinal striping.

Of equal importance, however, is the greater uniformity of surface conditions which may be achieved within a test series. By confining tests to a short, homogeneous length of roadway, significant differences in paint performance may be determined with improved precision. Transverse striping has thus become the generally accepted method for evaluation of traffic paints and was adopted for the present program.

Traffic paint vehicles have evolved from oleoresinous varnishes toward the synthetics, with current emphasis on the alkyds and with research interest directed toward newer types of synthetics. Federal Specification TT-P-00115b exemplifies the present state-of-the-art and includes vehicles of straight medium alkyd, chlorinated rubber modified alkyd, and plasticized butadiene-vinyl toluene resin. Much information has been accumulated from various testing programs concerning the effects of conventional formulation and application variables on paint performance. The present program was extended to include formulations based on recently developed paint vehicles such as epoxies and urethanes.

Night visibility is often considered to be of even greater importance than paint durability in evaluating traffic paint performance. Glass beads are uniquely effective in providing the retroreflective qualities essential for night visibility. Accordingly, studies of beading and bead retention were seen to be fundamental to performance evaluation. Reports of enhancement of paint durability by beading further stimulated interest in this subject.

II. OBJECTIVES

The primary objective of this series of highway tests was to provide field performance data on traffic paints for subsequent correlation with data from laboratory test methods. Of particular interest was a laboratory wear test procedure, described in Part III of this report. Although much valuable data on field performance is found in the literature, it was apparent that correlations of the required precision could be made only through direct experimental observations of identical paint systems in both laboratory and field.

Secondary objectives included the determination of the effects of selected parameters on traffic paint performance. Parameters included in this series were (1) variations in paint vehicle formulation, (2) comparisons of portland cement concrete and bituminous concrete as substrates, (3) effects of paint film thickness, and (4) comparisons of beading as opposed to no-beading on the test stripes.

III. EXPERIMENTAL PLAN

The experimental plan of this series was developed as follows:

1. Selection of Test Site. The required site would be a heavily traveled thoroughfare at a point where a bituminous concrete surface and a portland cement concrete surface adjoined and experienced equal traffic flow.

2. Formulation. Standard traffic paint formulation would be utilized, but the series would also include formulations based on recently developed paint vehicles.

3. Application. The test paints would be applied in parallel stripes at right angles to the direction of traffic flow. Special equipment would be designed and constructed for this purpose.

4. Substrate. Duplicate sets of stripes would be applied to the portland cement concrete and the bituminous concrete surfaces.

5. Film Thickness. Each paint would be applied at wet film thicknesses of 10, 15, and 20 mils (.010", .015", and .020"). Initial dry film thickness would then be determined from laboratory characterizations of the formulations.

6. Beading. Stripes would be beaded in standard manner, while a duplicate set would be left unbeaded.

As this plan was carried out, the number of formulations tested was 9. In order to test each formulation at 3 thickness levels, on 2 different substrates and at 2 beading levels (with and without), the total number of stripes required was 9 x 3 x 2 x 2 = 108.

7. Evaluation. At periodic intervals the test stripes would be evaluated with respect to measurable effects of traffic damage. Of particular interest in this series were the effects on paint film integrity and night visibility.

IV. FORMULATIONS AND PREPARATION

The paints included in this study were carefully selected to encompass all of the major generic types in current use by highway authorities. In addition, several novel types of distinctly speculative interest are included. Formulation details of each paint are given in Appendix A; Appendix B shows the infra-red spectra of the paint vehicles. From a broad survey of candidates, the following nine were selected for inclusion in Series I:

Paint No. 6

This paint, together with the formulation, was furnished by a materials supplier. Based on a butadiene-vinyl toluene vehicle, it is very similar to the specifications of several state highway departments. It dries entirely by solvent evaporation rather than by oxidation.

Paint No. 11

This tung oil varnish paint was utilized for many years by the State of Georgia and is of a general type that has exhibited good performance elsewhere. It dries by a combination of oxidation and solvent evaporation. Currently, the tung oil varnish is a relatively expensive vehicle that may be difficult to justify economically.

Paint No. 13

This paint was designed to be representative of a very fast drying lacquer type formulation which has found some usage on city streets to minimize traffic delays. Relatively poor durability was anticipated.

Paint No. 14

Paints based on catalyzed epoxy resins have gained a reputation for toughness and durability. This amine-cured formulation is representative of the type as formulated for traffic paint use.

Paint No. 15

This paint is based on a straight medium oil alkyd of the glycerol phthalate-linseed type. Vehicles of this type have gained wide acceptance for traffic paint applications.

Paint No. 16

The vehicle of this paint is a blend of a long oil alkyd resin with chlorinated rubber. The long oil alkyd resin alone would dry too slowly to be practical; however, it should have excellent durability, once dried. The chlorinated rubber modification accelerates drying to a satisfactory rate.

Paint No. 17

This is a very unconventional paint of a speculative character. The vehicle is a moisture-curing polyurethane resin and is so reactive that it could not be ground directly with pigments. The pigments were slurry-ground with a small amount of tolylene diisocyanate to neutralize all reactive sites prior to addition of the polyurethane vehicle. In spite of these precautions, the paint developed excessive bodying prior to application.

Paint No. 18

The epoxy polyamide vehicle of this paint is distinguised from the amine cured epoxy in the fact that the curing agent is also a resin. The polyamide resin reacts with the epoxy to form a resin "alloy." These "alloys" exhibit outstanding toughness and can also tolerate application to surfaces that are slightly damp.

Paint No. 19

The resin manufacturer supplied this paint, together with complete formulation data. Paint No. 19 differs from Formulation No. 14 in two important respects. First, its vehicle resins are solids rather than liquids; therefore, the paint is capable of "lacquer-drying" rapidly to a "no tracking" condition, even though the resins cure over a period of time. Second, the catalyst is an amine adduct that provides extended pot life and improved control of the curing reaction.

Preparation

Approximately 3/4 gallon of each paint was prepared in the laboratory by grinding in a one-gallon pebble mill. A minimum texture of Hegman 3 was developed. Weight per gallon and total solids were determined.

V. STRIPE APPLICATOR

The application requirements of the test stripes posed special mechanical problems. The paints should be applied in the same manner as with conventional striping equipment, which generally employs a spray delivery. This equipment must provide precise control of film thickness. It should be adaptable to paint systems of varying rheological properties and densities. It should have a small enough capacity to permit application from fractional gallon quantities, and it should permit easy changeover from batch to batch.

The sincere efforts of many investigators to attain prescribed film thicknesses in field testing highway paints have met with questionable success. Commercially available application equipment lacks many of the above requirements, particularly precise control of film thickness and adaptability to successive batches of varying rheological properties.

These requirements were met in this test series by a machine designed to meter paint to a spray head in precise proportion to the traverse of the spray head along the highway surface. A piston, geared to the wheels of the applicator carriage, delivers paint from a cylinder by positive displacement (Figure 1). As the carriage moves forward, the rotation of the front axle is transmitted through a speed reducing pulley and belt system to a floating pinion on the rear axle. This pinion drives forward a rack, surmounted by an inclined bar of variable pitch, which drives the piston upward, forcing paint through the material line to the gun. The pitch of the inclined bar controls the volumetric rate of paint delivery.

The applicator was required to have a capacity for only about 30 feet of continuous line. This factor, together with paint stripe width and thickness, determined the design dimensions of the machine. Paint is charged to the vertical cylinder through the funnel at the top. The cock below the funnel is then closed, and the piston is advanced with the gun nozzle open until all air is purged from the cylinder and material line, and paint is being delivered to the gun. A control cable on the handle of the carriage triggers the gun for delivery to the highway surface.

Beading was applied to the wet paint stripes by means of a Paint Bead Distributor (Figure 2) developed in this project. This equipment did not provide for precise metering of beads onto the stripe, but after some experimentation and adjustment of flow rates it was possible to attain the approximate level of beading desired.

Figure 1. Paint Stripe Applicator.

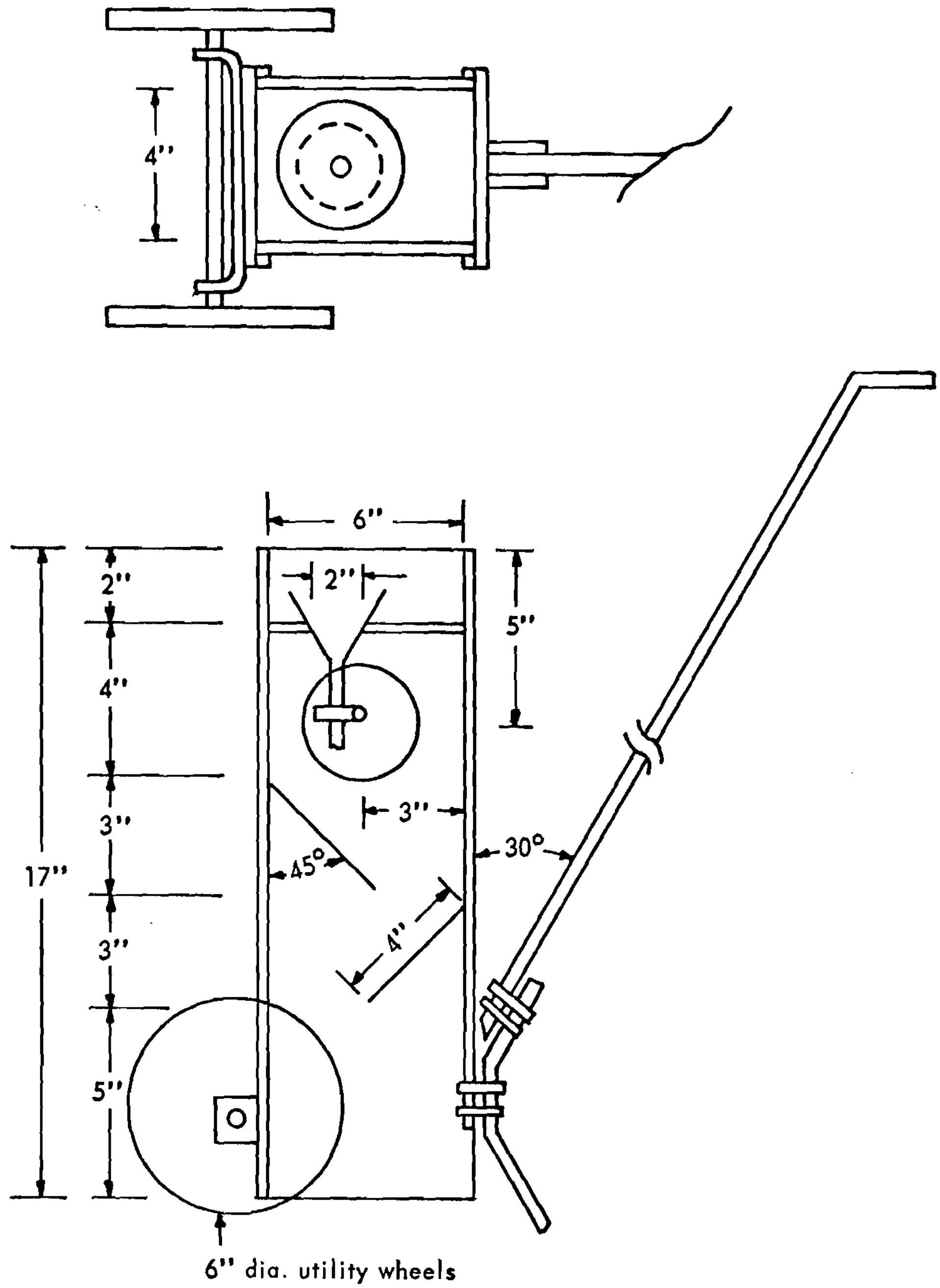

Figure 2. Paint Bead Distributor.

VI. SITE SELECTION AND APPLICATION

A suitable site for these tests was located on Atlanta's Northeast Expressway (Interstate 85) at the bridge over Lenox Road (Figure 3). This highway is paved with portland cement concrete to the south of the bridge and bituminous concrete to the north. It is one of the most heavily traveled arteries in the vicinity, carrying a traffic count of approximately 33,000 vehicles per day in the two northbound lanes.

On August 1, 1962, duplicate sets of transverse test stripes were applied to sections of the outer northbound lane immediately adjacent to the bridge, north and south. The proximity of the two sections and the absence of ramps between them provides assurance that virtually the same traffic will pass over both sections.

The paint stripe applicator was set to provide wet film thicknesses at nominal levels of 10, 15, and 20 mils. Duplicate stripes of each paint and each thickness were laid on each section; one stripe was left unbeaded, while the other was beaded at a nominal level of six pounds of beads per gallon. Gun stoppages interfered with application of the complete set of Paint No. 14. Paint No. 17 required field thinning before it could be handled by the equipment. Otherwise, the application proceeded in exact accordance with the experimental plan.

VII. EVALUATION METHODS

The paints were applied and evaluated in accordance with ASTM procedures and standards. These methods included:

D713-46: Conducting Road Series Tests on Traffic Paint.

D821-47: Abrasion, Erosion Resistance.

D913-51: Chipping Resistance.

D1011-52: Night Visibility.

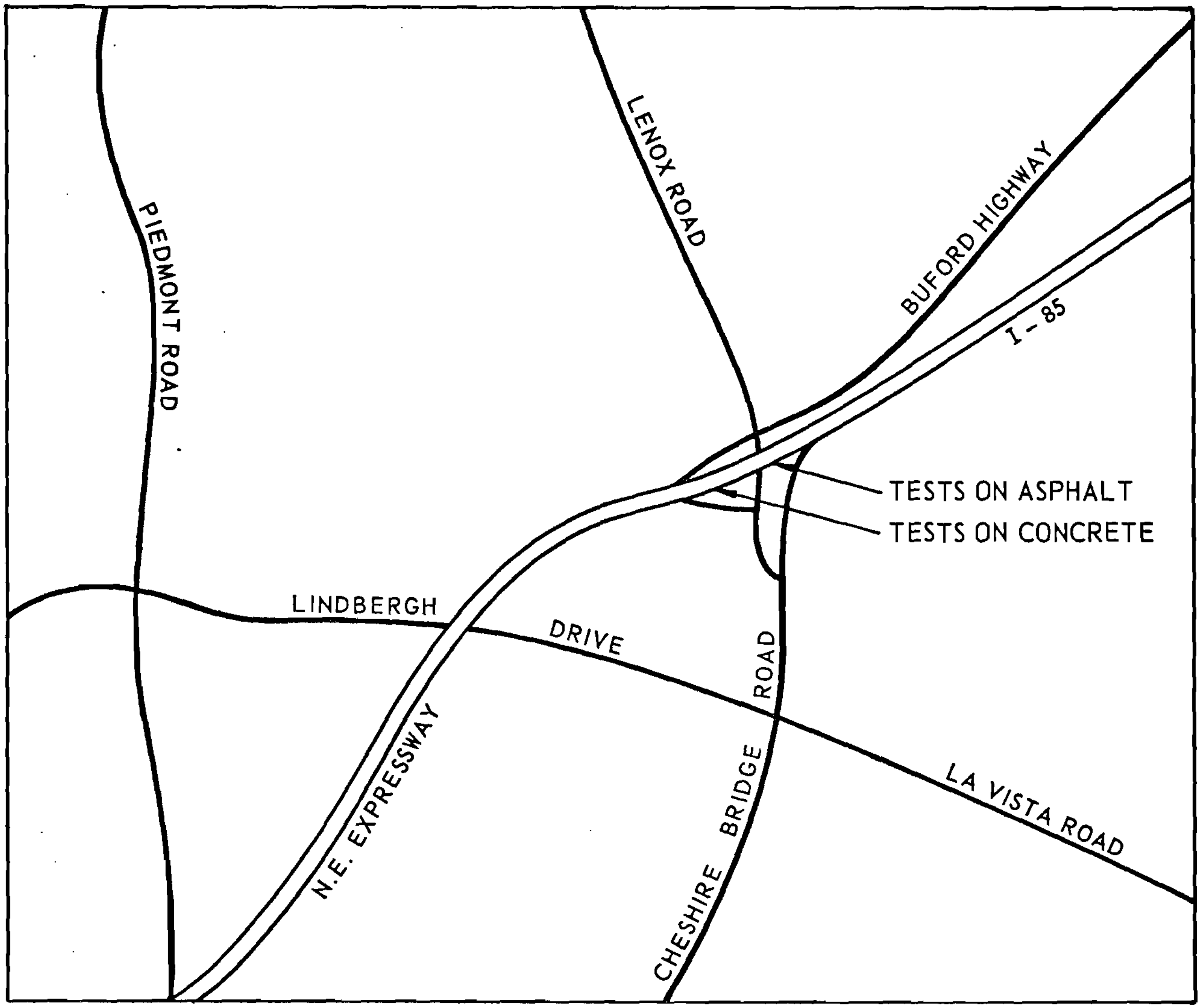

Figure 3. Location of Highway Tests.

Paint durability was estimated by visual inspection for paint loss. Each paint stripe was given a rating for chipping loss and/or a rating for abrasion loss, depending upon the types of failure observed. These readings were subsequently consolidated into a single value for "Paint Integrity" which represents the lower rating. Observations were limited to those areas of the stripes which are subjected to heaviest tire action; the extremes and the center (between treads) were not considered. Readings of night visibility were taken at three points spaced approximately one foot apart in the outer tread lane; the reported values are averages of these three readings.

VIII. TEST RESULTS AND OBSERVATIONS

Test results are tabulated in detail in Appendix C. Note that observations on the asphalt substrate were terminated by repaving operations after nine months. Photographs of the test stripes made at intervals during the exposure period are presented in Appendix D. The following summary relates performance results to paint type, film thickness, substrate type and beading.

A. Paint Type

Loss of paint film integrity was due to abrasive wear in most cases. Figure 4 shows average integrity values after nine months' service. Night visibility data for the same period are shown in Figure 5.

Satisfactory bead adhesion was secured only in Paints Nos. 15, 16, 17, and 18; therefore, night visibility results are significant only for these items. This does not infer that the other paints are necessarily incapable of retaining beads, but in this initial test series the paint surface may have become too dry for good adhesion. In subsequent series, beads were applied immediately to the wet stripes.

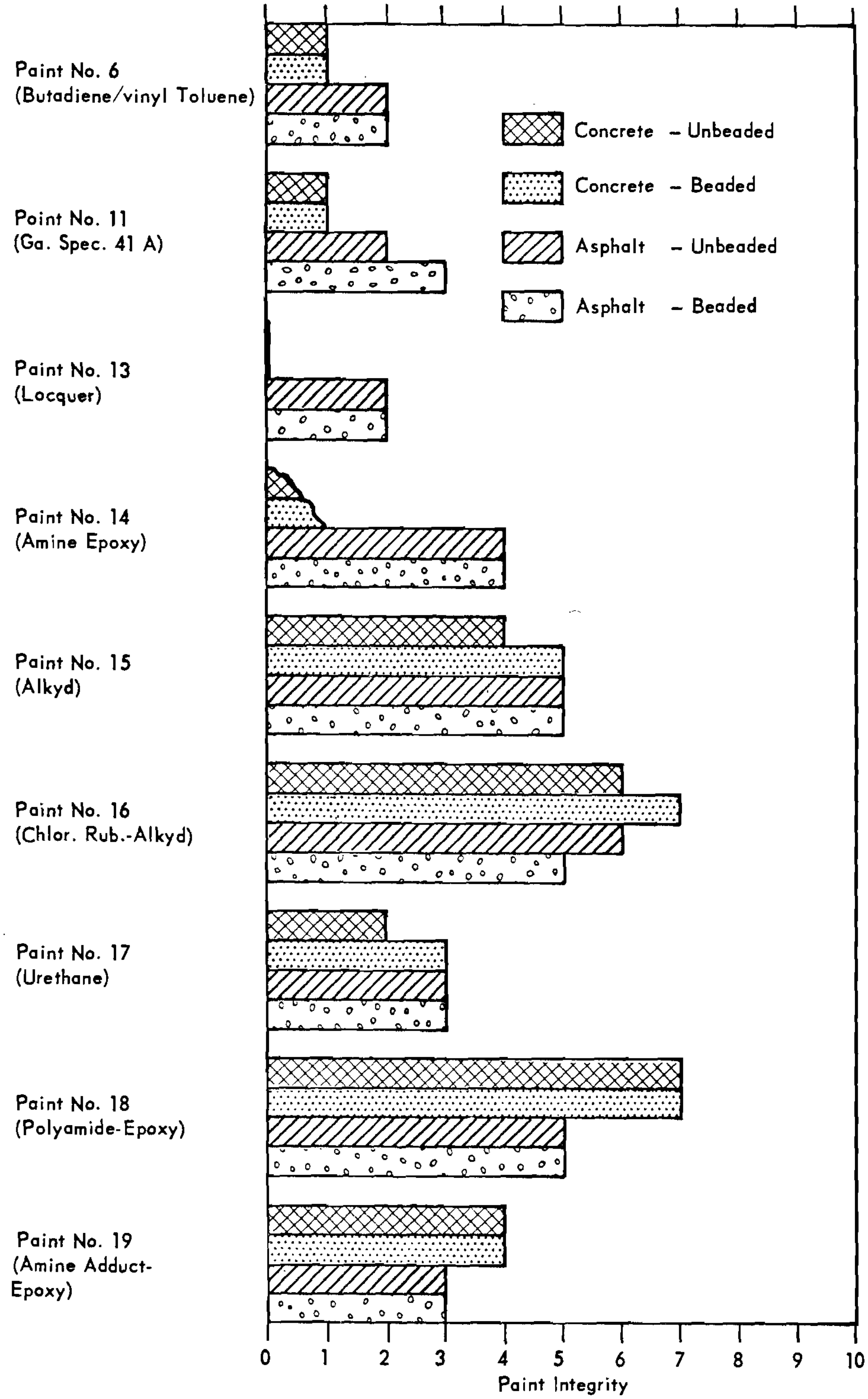

Figure 4. Paint Integrity at 9 Months' Exposure.

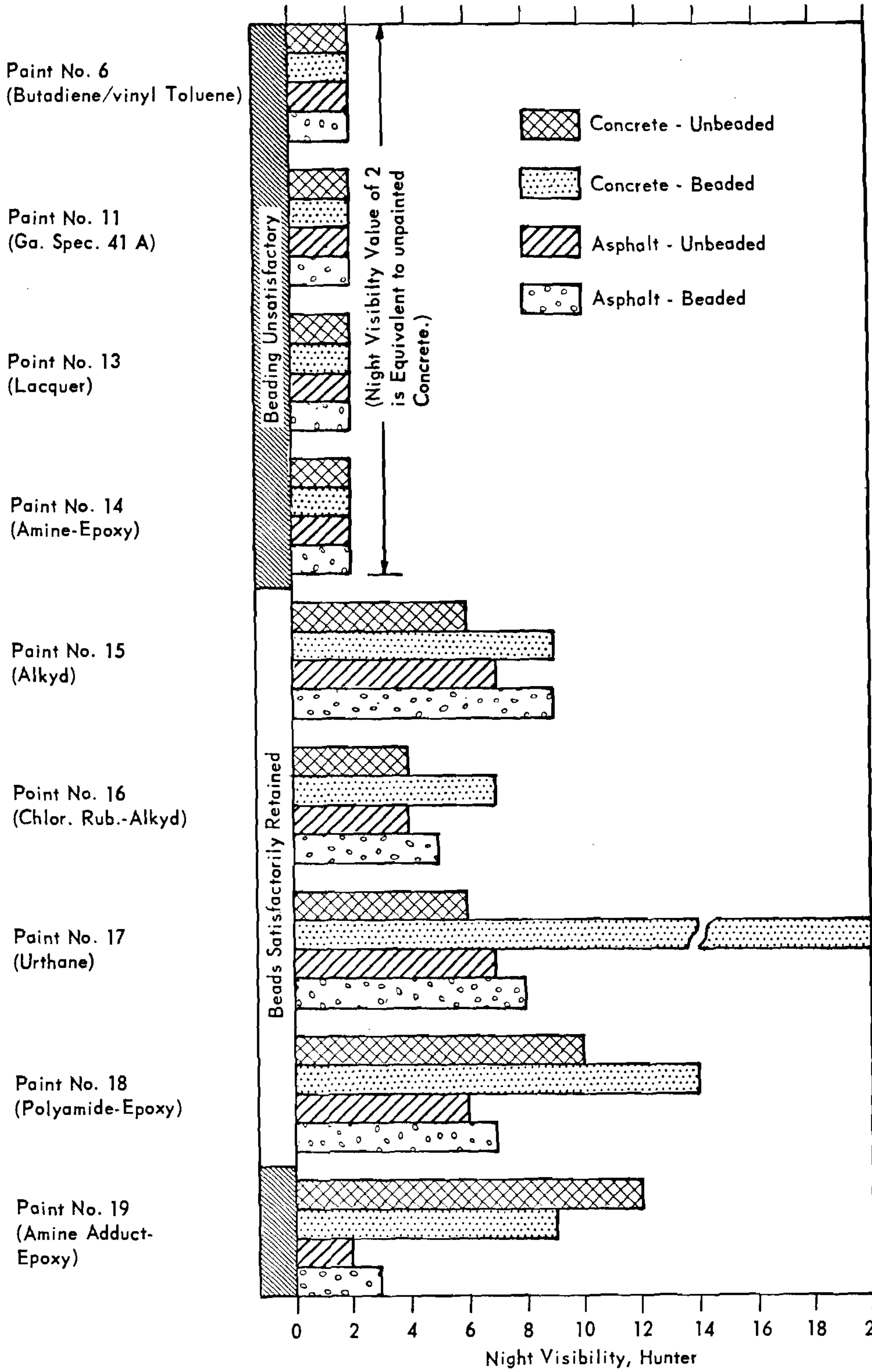

Figure 5. Night Visibility at 9 Months' Exposure.

The following observations concerning the individual paints are based on a twelve months' exposure period:

(1) The butadiene/vinyl toluene type paint (No. 6) and the Georgia Specification 41A paint (No. 11) were generally similar in performing at a level definitely below that of the best of the "conventional" formulations. Subsequent lab work suggests that paint No. 6 did not exhibit the full capabilities expected of this generic type paint.

(2) The lacquer type paint (No. 13) was the poorest performer in the group, both in film integrity and in night visibility. In this lacquer, as in Nos. 6, 11, 14, and 19, drying was too rapid for good bead adhesion.

(3) A straight alkyd (No. 15) and a chlorinated rubber modified alkyd (No. 16) were among the best of the paints tested. Compared to other conventional paints, the latter maintained particularly outstanding integrity on concrete. However, these paints were not equal to some of the "specials" in maintaining night visibility, particularly on concrete.

(4) Application problems were experienced with both the amine epoxy (No. 14) and the polyamide epoxy (No. 18), leading to deletion of some of the tests of No. 14 on concrete. Comparative judgments should be made only in the light of this observation. However, despite this difficulty, the polyamide epoxy was second only to the polyurethane paint (No. 17) in retention of night visibility on concrete, was among the highest in integrity on concrete, and showed good integrity on asphalt.

(5) Retention of night visibility on concrete and asphalt by Paint No. 17 is particularly noteworthy. This is believed to be the first highway test of a moisture curing polyurethane material to be conducted and reported. The paint exhibited a tendency to chip and was, therefore,

not rated superior in integrity; however, its resistance to abrasive wear was good. Unfortunately, package stability of the pigmented polyurethane remains a problem.

(6) The amine adduct epoxy (No. 19) at first appeared to be the most practical of the "special" types for possible service use. During the early months of the study its performance was excellent, but after twelve months' exposure it was below the alkyd paint in film integrity.

Regularly scheduled examinations and ratings of the paints were discontinued with the twelve months' observations, and a final examination was made at eighteen months. By this time almost all lines were completely eroded; of the entire series, only Paints Nos. 15 and 16 exhibited appreciable visible film.

B. Film Thickness

Figure 6 shows average values of integrity versus wet film thickness after 5 and 9 months' exposure and (on concrete only) at the end of 12 months. These values indicate that, even at 20 mils wet film thickness, there is a continuing trend toward improvement of durability with increasing film thickness.

Average night visibility versus film thickness for those paints which retained beads (Nos. 15, 16, 17, and 18) is shown in Figure 7 at several observation periods. The values for paints on concrete at 5 months and at 9 months are significantly higher than the corresponding values on asphalt. Although rather poor precision was a characteristic of night visibility data, a general trend toward increased values with increasing film thickness is indicated. An examination of the detailed observed data (Appendix C) suggests that the beading was not uniform

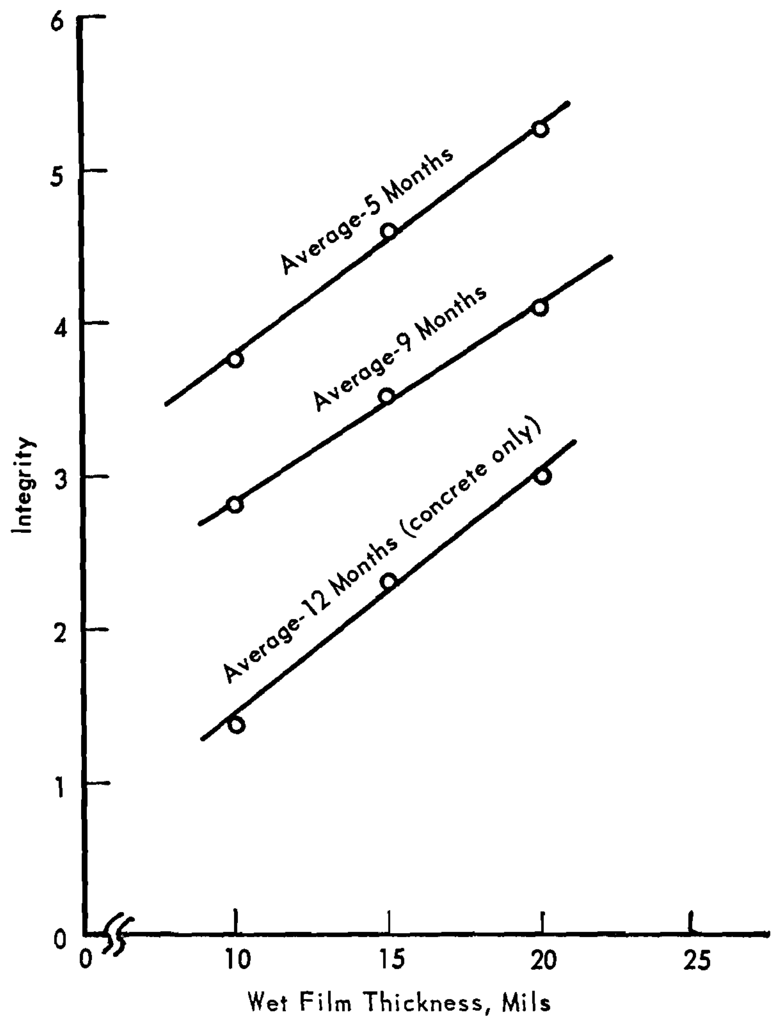

Figure 6. Average Integrity Values versus Wet Film Thickness.

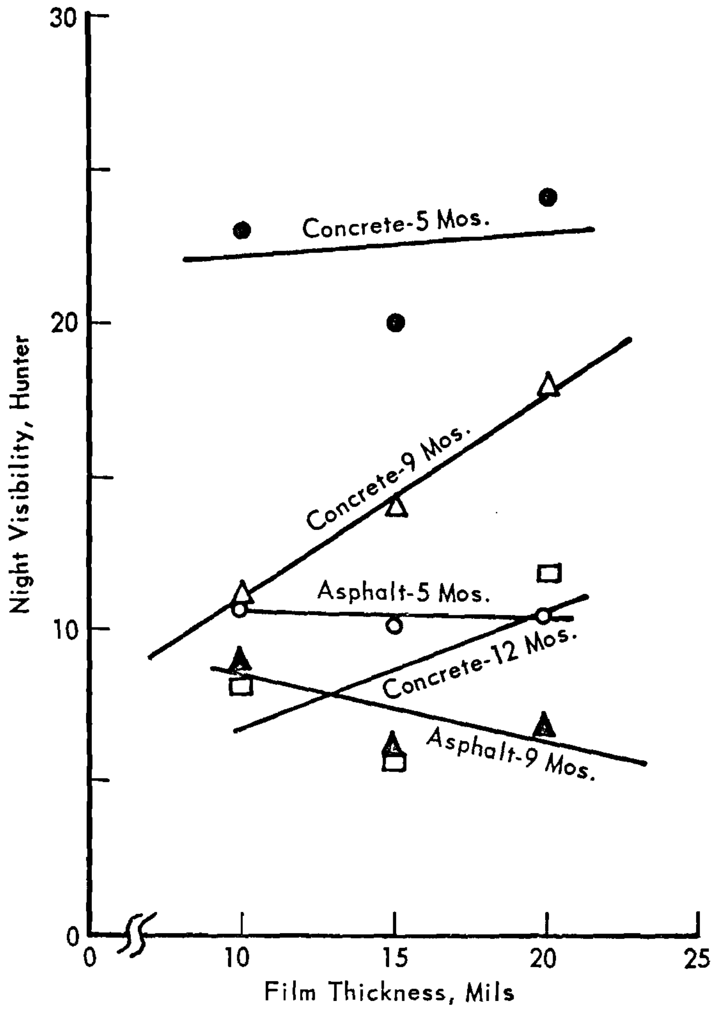

Figure 7. Night Visibility versus Wet Film Thickness for Paints 15, 16, 17, and 18, Beaded Stripes Only.

initially, and the 15 mil thickness values were biased low by at least one instance (concrete, Paint No. 18) of inadequate original beading. The more durable paints (Nos. 15, 16, 17, 18) were found to exhibit a relatively constant high level of both night visibility and integrity, and the thickness effect becomes evident only with longer weathering. The distinctly greater integrity of the 20 mil films of these paints at 12 months may be noted in Table VII in Appendix C.

C. Substrate Type

The data presented in Figure 4 through 7 tend to show an average superior performance for paints on concrete rather than asphalt. This is definitely not in agreement with historical experience on this subject.* A more detailed examination of Figure 4, however, shows that the "conventional" paints (Nos. 6, 11, 13, 15) do, indeed, follow the classical pattern of better performance on asphalt; it is the "special" paints which reversed the pattern and weighted the averages. In addition to their relatively superior performance on concrete at nine months' weathering, the "specials" were still almost equal in integrity to the best conventional paints on asphalt. Unfortunately, further observations on asphalt were terminated at this time by repaving operations on the asphalt stretch of I-85.

D. Beading

Much of this subject has been covered in the preceding discussions, but the following points deserve emphasis:

(1) Superior bead retention, as measured by night visibility, was exhibited by the "special" paints, and particularly by the polyurethane (No. 17).

*Goetz, W. H., "Field and Laboratory Investigation of Traffic Paints," Proceedings, Highway Research Board 21, 233-259 (1941).

(2) Bead retention on concrete was superior to that on asphalt, for the limited group studied. This parallels the superior integrity of these items on concrete.

(3) Quantitative conclusions about bead retention and its effects on durability are reserved for further study, since in most cases it was evident that too rapid drying of the paint stripes had interfered with proper adhesion of the beads.

IX. DISCUSSION AND CONCLUSIONS

The study described in this report was, for this laboratory, an initial exploration of a specialized field of surface coatings. In spite of a rather broad background in the general field of coatings science, the special nature of this investigation required extensive study of information sources, devising and screening materials and methods for the experimental program, designing and constructing equipment for laboratory and field use in the experiments, refining the evaluation techniques, and a continuing process of learning and feedback to improve procedures. The formulation and testing of highway marking materials are beset with numerous problems, some aspects of which were not encountered in previous literature. These unanticipated problems had to be interpreted and dealt with as each arose. The results obtained and the conclusions to which they led are, nevertheless, a significant contribution to this field and provide constructive information for the formulation and application of traffic paints.

Equipment designed and constructed in the course of this project has already served in subsequent experiments and will probably continue to be used as additional studies along these lines are conducted. Of particular interest are the paint stripe applicator and the bead distributor. These devices have performed satisfactorily, although slight modifications are indicated should they be incorporated in further studies. The laboratory wear tester, constructed concurrently with this program, is described in Part III of this report. The beta-backscatter gage, based upon a design of Pocock, may well find use in other areas, although it proved unsuitable for use with traffic paints.

When viewed in retrospect, means of improvement in planning and execution of experimental programs are usually obvious; the present study is no exception. The most serious shortcoming of this study was the inadequate beading obtained on most of the conventional paints. Because of the substantial effects of beading on film integrity as well as night visibility, the utility of most of the highway tests of conventional paints for correlation with accelerated laboratory wear tests is limited. These limitations were recognized early in the study, and a second series of highway tests was started to provide supplementary information.

In general however, this study met the objectives of providing useful data for correlating with laboratory wear tests, and helpful information on formulation, film thickness, and surface type. Specific conclusions related to these objectives are as follows:

A. Correlation

1. Suitable data for lab-highway correlations were obtained for all paints tested, if comparisons are limited to a "no beads" basis.

2. Only paints numbered 15, 16, 17, and 18 yielded suitable data for correlation of performance on a "beads on" basis.

3. Results of correlation studies of this series will be included, along with those of subsequent series, in Part III of this report.

B. Evaluation of Selected Variables

1. Formulation. Straight alkyd and chlorinated rubber modified alkyd types exhibited outstanding overall performance, but special paints based on epoxy and on polyurethane vehicles displayed interesting bead retention properties.

2. Film Thickness. A general increase in both integrity and night visibility was observed with increasing film thickness between 10 and 20 mils.

3. Surface type. Conventional traffic paints tend to perform better on asphalt surfaces than on concrete. Certain formulations based on special vehicles performed better on concrete than on asphalt, but, even on asphalt, were still superior to most conventional paints. Known basic differences in adhesion and toughness of these special vehicles could account for these differences.

4. Beading. When initial bead retention is good, beading enhances the durability of a traffic paint as well as providing the essential property of night visibility.

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XI. APPENDIXES

A. Paint Formulations

B. Infrared Spectra of Vehicles

C. Tabulations of Test Results

D. Photographs of Stripes

A. Paint Formulations

Project No. B-210

Date May 7, 1962

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 6

White Vinyl Toluene/Butadiene Traffic Paint

BX 85-J-98

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT							
Titanox RCHT			296				
Titanox RANC			59				
Fibrene C-400			53				
Celite 261			83				
Mineralite 3X			59				
Bentone 38			5				
VEHICLE							
Pliolite VT-L			107				
Velsicol X-37			35				
Chlorinated Paraffin, 40%			35				
Soya Lecithin			8				
Tolusol			357				
			1097				

WEIGHT PER GALLON 11.0 LBS.

P.V.C. 51.5 %

TOTAL SOLIDS:

WEIGHT ______ %

VOLUME ______ %

Project No. B-210

Date

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 11

Ga. specification 41A, White

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
PIGMENT	55.0						
ZnO	5						
Asbestine	25						
Lithopone	55						
TiO_2	15						
	100						
VEHICLE	45.0						
Synthetic resin	20.2						
Tung oil	22.5						
Conc. (cobalt) Naphtha	2.3						
Petroleum Naphtha	41.3						
Benzol	13.8						
	100.1						

WEIGHT PER GALLON ____________ LBS.

P.V.C. ____________ %

TOTAL SOLIDS:

WEIGHT ____________ %

VOLUME ____________ %

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 13

Lacquer type traffic paint, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	25.7	10.4				
Rutile 610 - TiO_2	24.7	17.1	63.0	35.0	1.8	299
Gamaco	54.1	58.1	137.9	22.6	6.1	655
Celite 281	9.8	12.4	25.0	19.2	1.3	120
Nytal 300	10.3	10.5	26.2	23.8	1.1	123
Bentone 27	1.1	1.9	2.8	14.2	0.2	13
	100.0	100.0	254.9		10.5	1210
VEHICLE	74.3	89.6				
1/2 sec N/C - 25%	50.5	47.3	373.2	8.7	42.9	1777
Amberol 800 - 50%	9.3	9.2	69.0	8.3	8.3	328
Flexol 8HP	10.6	10.1	78.2	8.5	9.2	372
Lacquer Thinner*	29.5	33.3	217.9	7.2	30.2	1035
Ethanol 10						
Butanol 5			738.3		90.7	3512
Ethyl Acetate 20						
Butyl Acetate 15						
Toluene 50						
	99.9	99.9	993.1		101.2	4722

300 g thinner used for grinding.

WEIGHT PER GALLON 9.8 LBS.

P.V.C. 47.5 %

TOTAL SOLIDS:

WEIGHT 38.5 %

VOLUME 21.8 %

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 14

Epoxy Amine, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	47.6	22.7				
Rutile 610 - TiO_2	21.6	16.1	150	35.0	4.65	680
Gamaco	32.1	34.1	223	22.6	9.87	1030
Celite 281	10.5	13.2	73.2	19.2	3.81	332
Nytal 300	34.9	35.2	242.5	23.8	10.19	1100
Bentone 27	0.9	1.5	6.0	14.2	.42	27
	100.0	100.1	694.7		28.94	3168
VEHICLE	52.4	77.3				
Araldite 571 - T - 75	42.6	35.5	325	9.3	35.0	1475
Methyl Ethyl Ketone	26.3	30.9	201	6.6	30.5	910
Toluene	25.7	28.0	196	7.25	27.6	890
U F Beetle 216 - 8	1.6	1.4	12	8.6	1.4	54
Butanol	1.9	2.3	14.7	6.5	2.25	67
Diethylene Triamine	1.9	1.8	14.7	8.2	1.80	67
			763.4		98.55	3463
	100.0	99.9	1458.1		127.49	6631

1500g MEK, toluene used for grinding,
Beetle added after grinding,
2.1g catalyst for 100g batch.

WEIGHT PER GALLON 11.4 LBS.

P.V.C. 53.1 %

TOTAL SOLIDS:

WEIGHT 64.8 %

VOLUME 42.6 %

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 15

Straight Alkyd, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	48.0	21.2				
Rutile 610 - TiO_2	29.8	20.8	150	35.0	4.3	680
Gamaco	29.8	32.4	150	22.6	6.7	680
Celite 281	19.8	25.1	100	19.2	5.2	454
Nytal 300	19.8	20.3	100	23.8	4.2	454
Bentone 38	0.8	1.4	4	15.0	0.3	18
	100.0	100.0	504		20.7	2286
VEHICLE	52.0	78.8				
Alkyd P 670-55	69.1	65.8	377	7.5	50.3	1710
VM & P Naphtha	28.2	32.0	154	6.3	24.5	700
Cobalt Naphth. - 6%	0.5	0.5	3.0	8.0	0.4	13.6
Lead Naphth. - 24%	1.4	1.0	7.5	9.6	0.8	34
Mn Naphth. - 6%	0.2	0.3	1.0	8.1	0.2	4.5
Adv. Anti-skin agent	0.6	0.5	3.5	7.8	0.4	15.9
			546.0		76.6	2478.0
	100.0	100.1	1050		97.3	4764.0

200g VM & P used for grinding

WEIGHT PER GALLON 10.8 LBS.

P.V.C. 48.0 %

TOTAL SOLIDS:

WEIGHT 68.1 %

VOLUME 44.3 %

Project No. B-210

Date 6/22/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 16

Parlon Alkyd Traffic Paint, White

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	grams
PIGMENT	60.2	32.6				
Rutile - 610 TiO_2	24.8	17.2	208	35.0	5.9	786
Gamaco	54.8	59.3	460	22.6	20.4	1739
Nital 300	10.0	10.2	83.5	23.6	3.5	316
Celite 281	10.0	12.5	83.5	19.2	4.3	316
Bentone 38	0.5	0.9	4.0	15.0	0.3	15
	100.1	100.1	839.0		34.4	3172
VEHICLE	39.8	67.4				
Parlon S-10 30% in toluene						
Toluene	19.5	21.0	108	7.25	14.9	408
Parlon S-10	8.4	4.8	46.4	13.6	3.4	175
Alkyd P - 296 - 70	51.6	52.3	286	7.7	37.1	1081
Toluene	19.1	20.6	106	7.25	14.6	400
Propylene Oxide	0.5	0.6	3	7.5	0.4	11
Co Naphth. - 6%	0.3	0.3	1.5	8.0	0.2	6
Adv. Anti-skin agent	0.5	0.6	3	7.8	0.4	11
			553.9		71.0	2092
	99.9	100.2	1392.9		105.4	5264

300g toluene for grinding

WEIGHT PER GALLON 13.2 LBS.

P.V.C. 56.7 %

TOTAL SOLIDS:

WEIGHT 77.9 %

VOLUME 57.3 %

Project No. B-210

Date 6/29/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 17

Polyurethane Traffic, White

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	44.3	20.1				
R- 610 TiO_2	47.4	35.1	207	35.0	5.92	940
Gamaco	31.4	35.8	137	22.6	6.04	622
Celite 281	19.9	26.9	87	19.2	4.55	395
Bentone 27	1.2	2.2	5.4	14.2	.38	25
			436.4		16.89	1982
	99.9	100.0				
VEHICLE	55.7	79.9				
Tolylene Diisocyanate	2.4	2.2	13	8.5	1.5	59
~~Toluene~~	28.1	31.6	154	7.25	21.2	700
*Spenkel M86 - 50CX	69.7	66.2	382	8.6	44.40	1734
			549		67.1	2493
	100.2	100.0	985.4		84.0	4475

700g Toluene used for grinding

*Pigments are slurry-ground with T.D.I. prior to incorporation of Spenkel.

WEIGHT PER GALLON 11.7 LBS.

P.V.C. 45.9 %

TOTAL SOLIDS:

WEIGHT 63.7 %

VOLUME 43.8 %

Project No. B-210

Date 6/29/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 18

Epoxy Polyamide, White

	% WEIGHT	% VOLUME	100 GALLON BATCH: Pounds	Lbs. Per Solid Gal.	Gallons	lab batch
PIGMENT	53.5	28.6				
Rutile - 610 - TiO_2	29.4	20.5	145	35.0	4.15	659
Gamaco	29.4	31.7	145	22.6	6.42	659
Celite 281	20.1	25.5	99	19.2	5.17	450
Nytal 300	20.1	20.6	99	23.6	4.17	450
Bentone 27	1.1	1.8	5.3	14.2	.37	24
	100.1	100.1	493.3		20.28	2242
VEHICLE	46.5	71.4				
Polyamide 815	24.5	25.5	105	8.1	12.9	477
Toluene	15.4	18.0	66	7.25	9.1	300
Cellosolve Solu.	15.4	17.0	66	7.7	8.6	300
U. F. Beetle 216 - 8	1.6	1.5	6.7	8.6	.78	30
Araldite 502	43.2	38.1	185	9.56	19.3	840
			428.7		50.68	1947
	100.1	100.1	922.0		70.96	4189g.

600g thinner used for grinding,
Beetle added after grinding.
30.5g catalyst for 100g of batch.

WEIGHT PER GALLON 13.0 LBS.

P.V.C. 39.0 %

TOTAL SOLIDS:

WEIGHT 85.4 %

VOLUME 74.7 %

Project No. B-210

Date 7/2/62

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 19

EPON resin formulation XYA-200
white traffic paint
(Supplied by Shell Chemical Co.)

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	52.5	25.0				
RCHTX - TiO_2	60.9	57.7	386	26.9	14.3	1752
Asbestine 3X	38.8	41.5	246	23.9	10.3	1117
Al. Stearate #909	0.3	0.8	2	10.0	0.2	9
			634		24.8	2878
	100.0	100.0				
VEHICLE	47.5	75.0				
EPON 1001-A-80	20.8	17.4	119	9.3	12.93	540
EPON 1007-CT-55	30.2	27.7	173	8.4	20.57	785
Acetone	33.2	38.9	190	6.6	28.9	863
Toluene	12.2	13.0	70	7.25	9.6	318
Beetle 216-8	1.7	1.5	10	8.5	1.1	45.4
Curing Agent U	1.9	1.8	11	8.5	1.3	50
			573		74.4	2601.4
	100.0	100.3	1207		99.2	5479.4

WEIGHT PER GALLON 12.2 LBS.

P.V.C. ______ %

TOTAL SOLIDS:

WEIGHT 68.8 %

VOLUME ______ %

B. Infrared Spectra of Vehicles

Figure 8. Infra-Red Spectrum of Vehicle
of Paint #6
Material Type: Butadiene-Styrene Polymer,
60% by weight
Petroleum Resin, 20% by
weight
Chlorinated Paraffin, 20%
by weight
Approximate Dry Film Thickness, mils: 0.7

Figure 9. Infra-Red Spectrum of Vehicle
of Paint #16
Material Type: Long-oil Alkyd Modified
with Chlorinated Rubber
Approximate Dry Film Thickness, mils: 0.3

Figure 10. Infra-Red Spectrum of Alkyd
Component of Paint #16
Material Type: Long-oil Alkyd
Approximate Dry Film Thickness, mils: 0.1

Figure 11. Infra-Red Spectrum of Vehicle
of Paint #17
Material Type: Moisture Curing Polyurethane
Approximate Dry Film Thickness, mils: 0.2

Figure 12. Infra-Red Spectrum of Vehicle
of Paint #18
Material Type: Epoxy-Polyamide
Approximate Dry Film Thickness, mils: 0.3

Figure 13. Infra-Red Spectrum of Amide
Component for Paint #18
Material Type: Amide Resin
Approximate Dry Film Thickness, mils: 0.4

Figure 14. Infra-Red Spectrum of Epoxy
Component for Paint #18
Material Type: Epoxy Resin
Approximate Dry Film Thickness, mils: 0.3

Figure 15. Infra-Red Spectrum of Vehicle
of Paint #19
Material Type: Epoxy-Amine Adduct
Approximate Dry Film Thickness, mils: 0.3

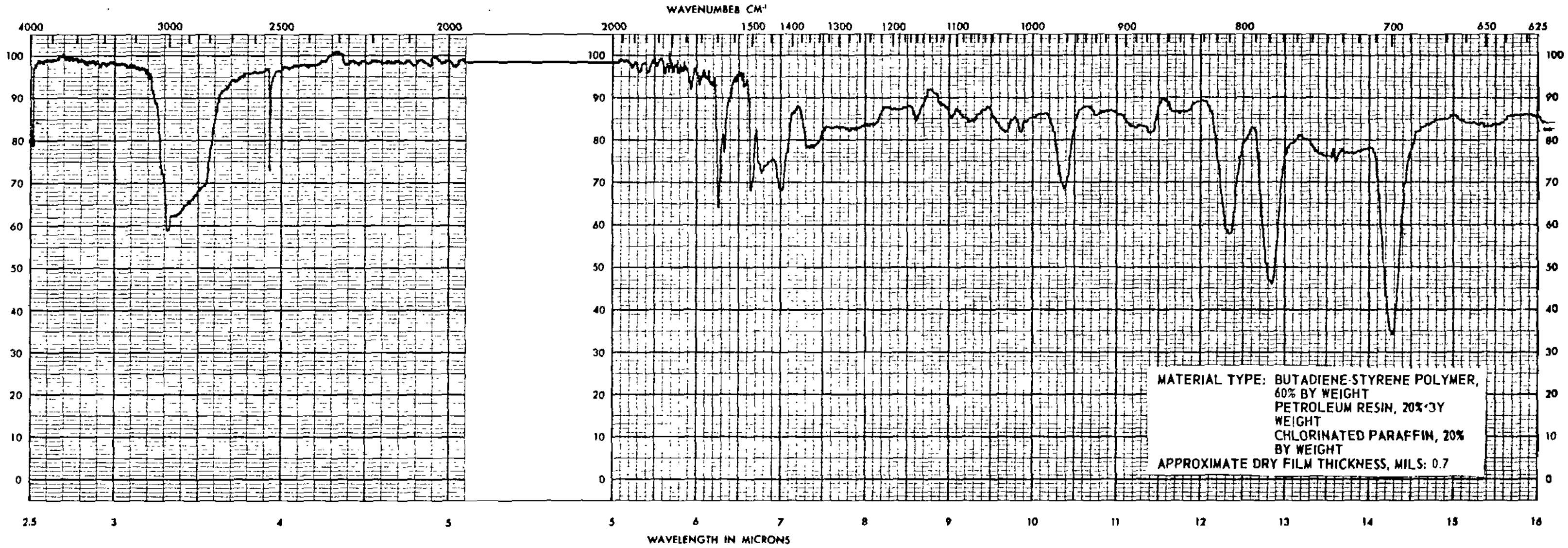


Figure 8. Infra-Red Spectrum of Vehicle of Paint #6.

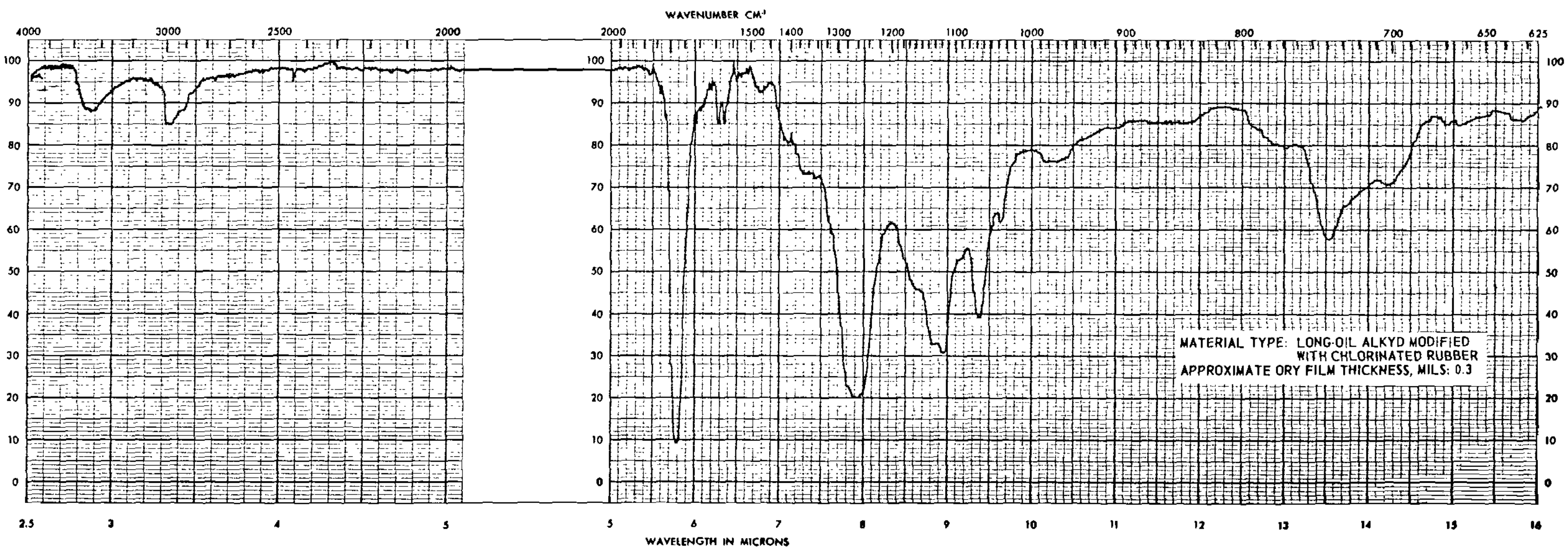


Figure 9. Infra-Red Spectrum of Vehicle of Paint #16.

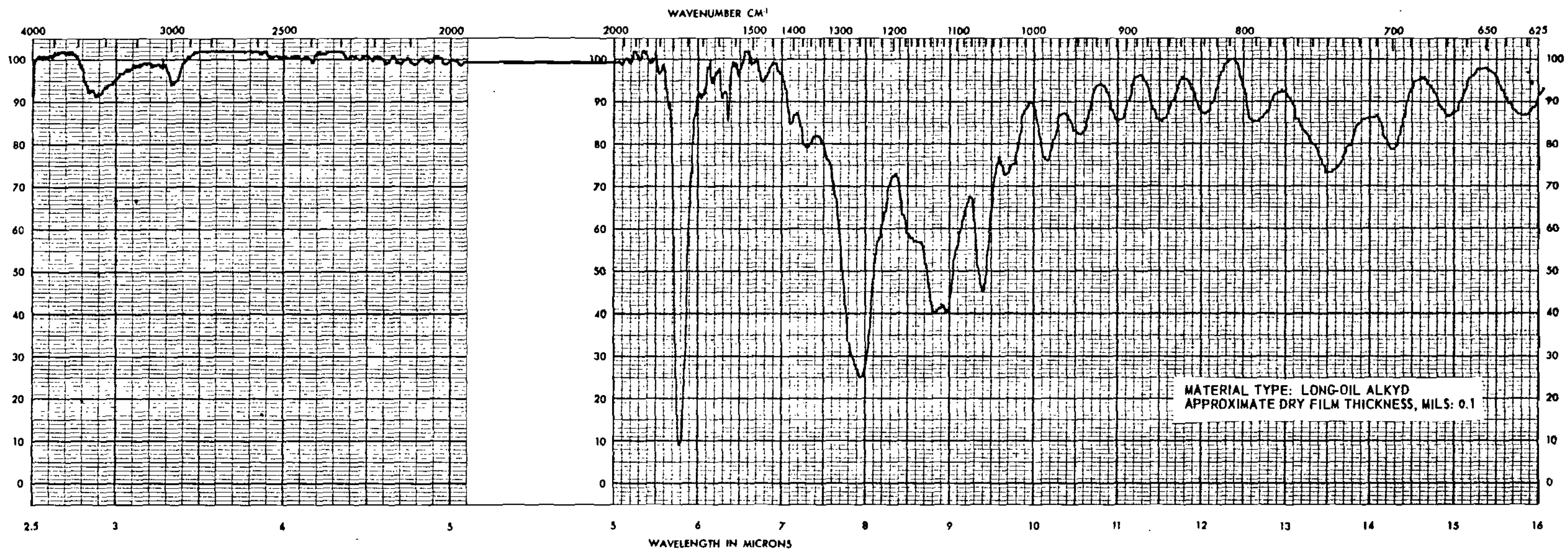


Figure 10. Infra-Red Spectrum of Alkyd Component of Paint #16.

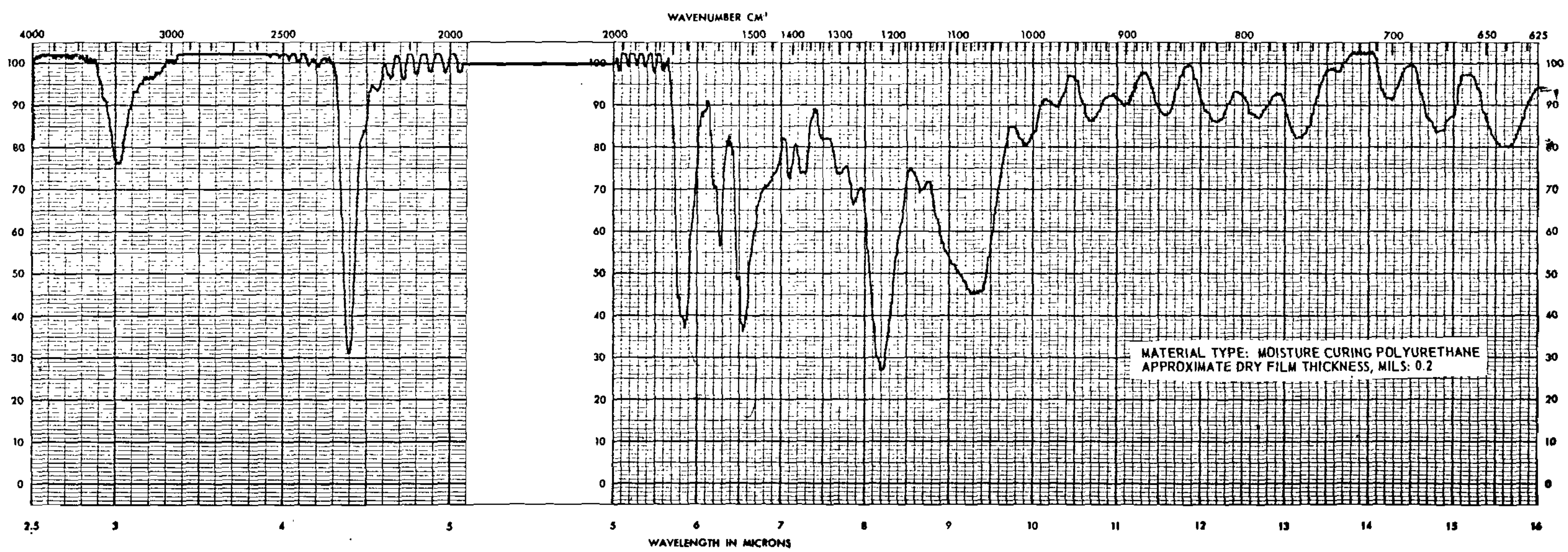


Figure 11. Infra-Red Spectrum of Vehicle of Paint #17.

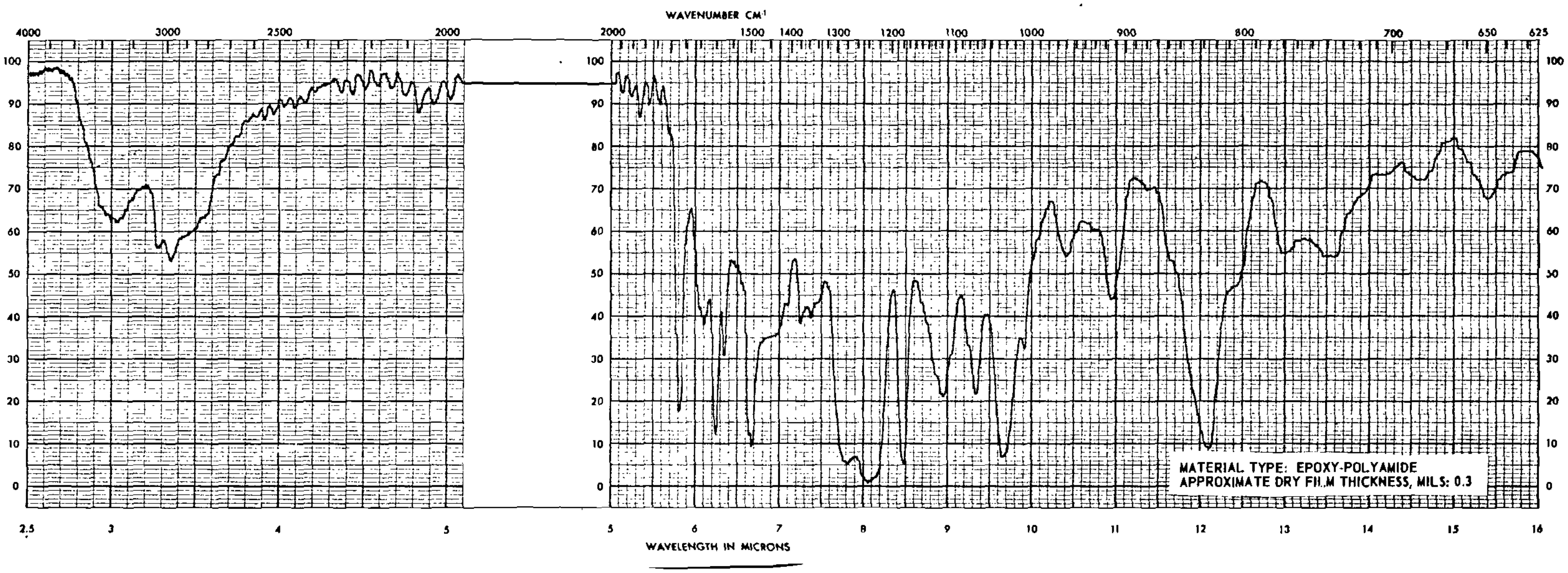


Figure 12. Infra-Red Spectrum of Vehicle of Paint #18 .

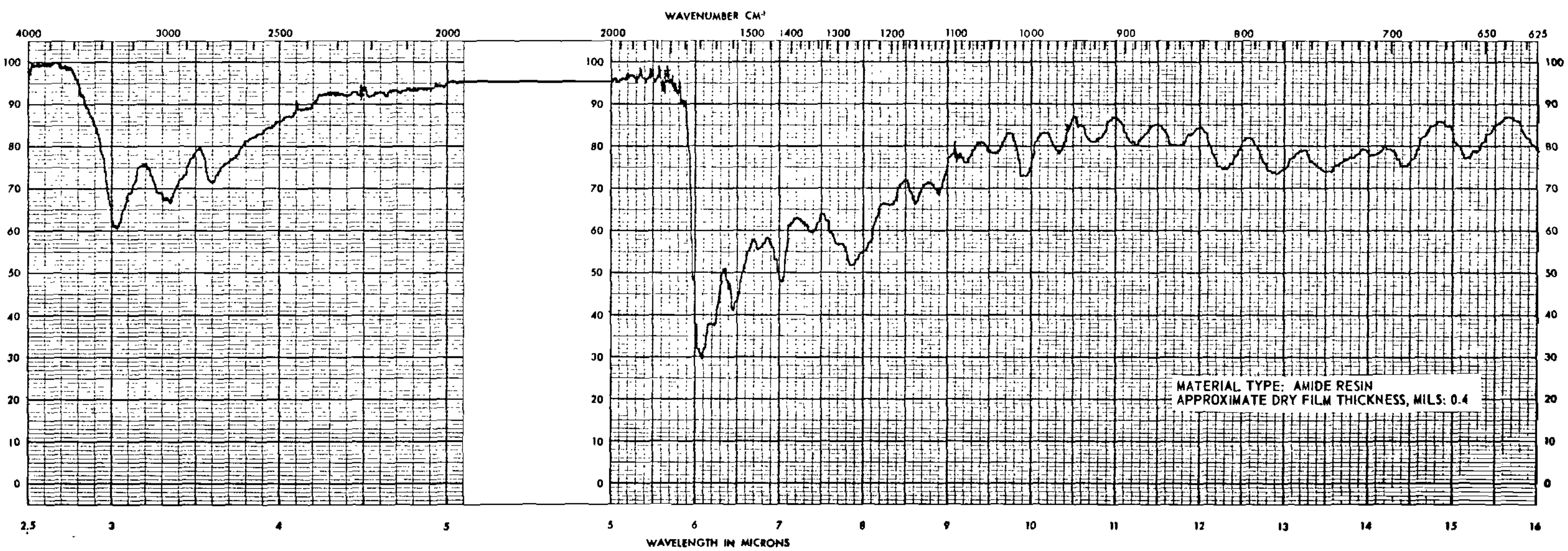


Figure 13. Infra-Red Spectrum of Amide Component for Paint #18.

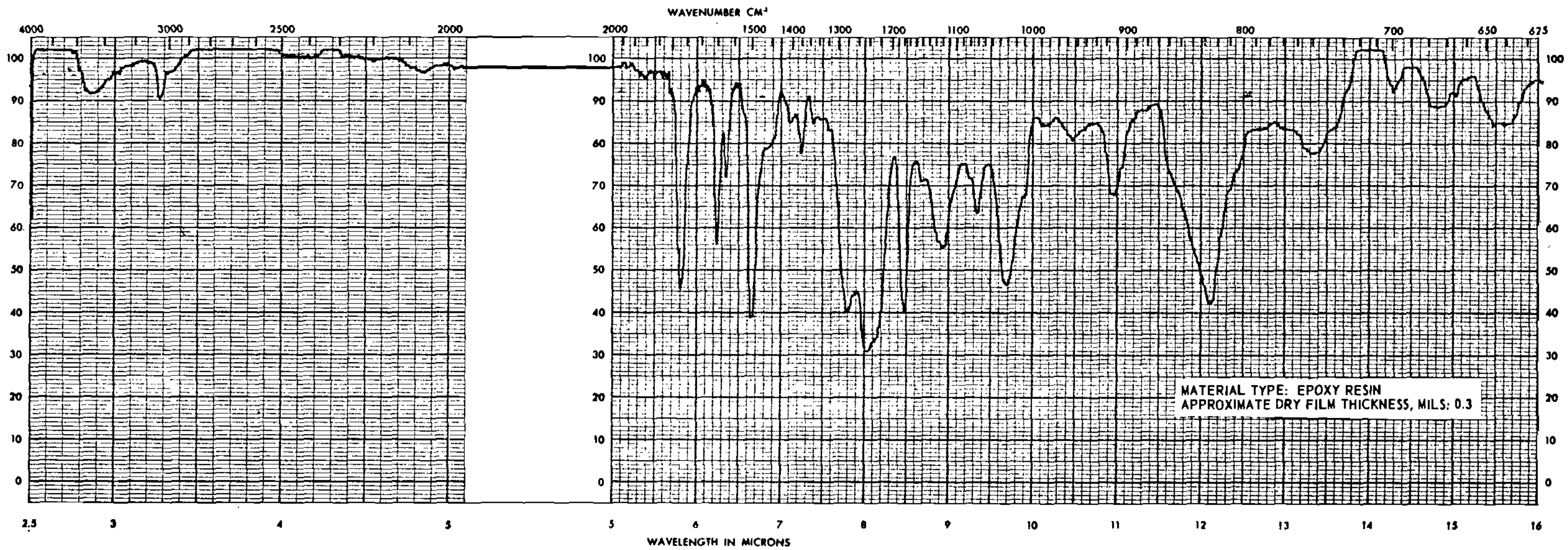


Figure 14. Infra-Red Spectrum of Epoxy Component for Paint #18.

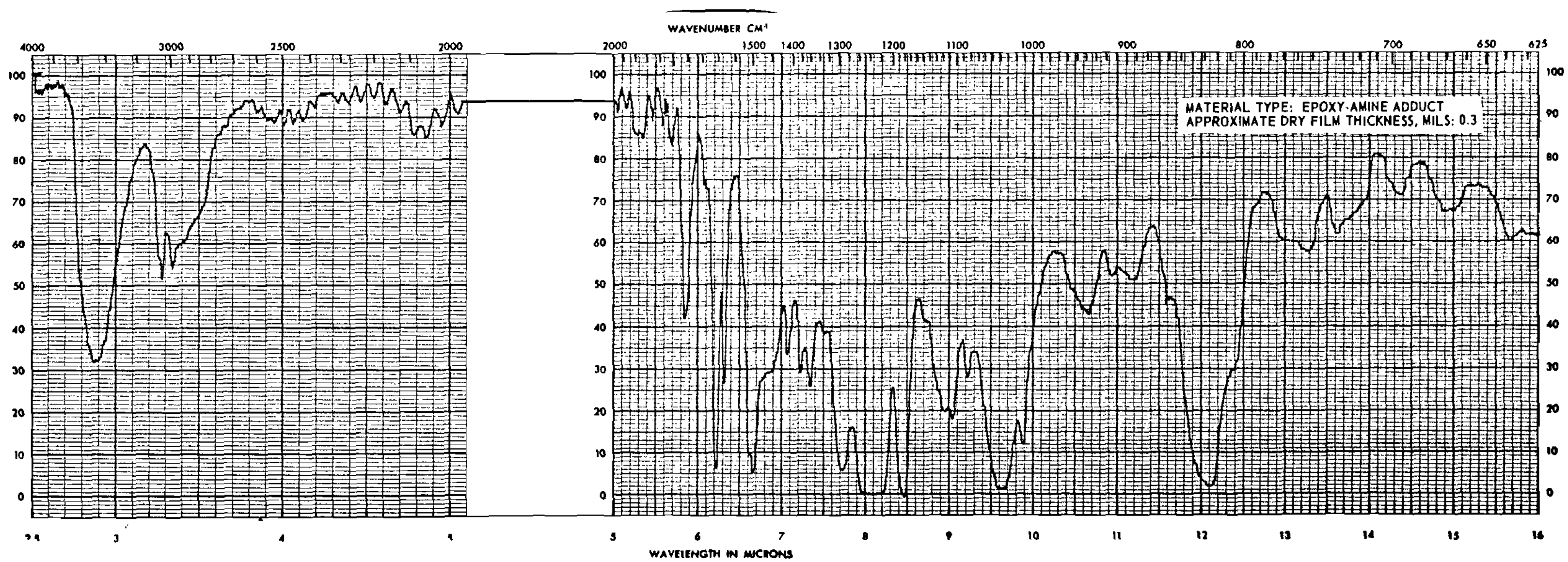


Figure 15. Infra-Red Spectrum of Vehicle of Paint #19.

C. Tabulations of Test Results

TABLE I

COMPLETE HIGHWAY TEST DATA AT 1 MONTH

Paint Type	Butadiene/Vinyl Toluene		Ga. Spec.		Lacquer		Amine Epoxy		Straight Alkyd		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
						A. Highway Test Film Integrity												
Concrete																		
10 mils	4	5	6	6	4	4	-	-	4	5	10	9	6	8	8	8	9	9
15 mils	8	8	7	9	5	5	-	-	10	10	10	10	5	8	8	8	9	9
20 mils	9	8	10	8	5	5	-	-	10	10	10	10	6	7	8	8	9	9
Average	7	7	8	8	5	5	-	-	8	8	10	10	6	8	8	8	9	9
Asphalt																		
10 mils	3	3	5	5	3	3	9	8	10	9	8	8	5	5	7	7	9	9
15 mils	8	8	8	8	6	6	8	8	10	9	9	9	5	5	7	7	9	9
20 mils	9	9	9	9	6	7	-	-	10	10	10	10	5	5	7	7	9	9
Average	8	8	7	7	5	5	8	8	10	9	9	9	5	5	7	7	9	9
						B. Highway Night Visibility Test												
Concrete																		
10 mils	4	5	3	6	3	4	-	-	6	19	5	11	7	52	4	80	6	5
15 mils	6	8	4	5	4	5	-	-	5	63	2	15	5	25	4	7	6	6
20 mils	6	6	3	5	4	3	-	-	6	15	2	38	7	73	8	42	4	6
Average	5	6	3	5	4	4	-	-	6	32	3	21	6	50	5	43	5	6
Asphalt																		
10 mils	5	6	4	6	4	3	4	4	5	33	3	10	3	62	14	23	3	3
15 mils	8	6	5	7	2	2	4	3	5	27	3	5	3	47	10	8	2	3
20 mils	6	5	5	7	2	2	-	-	4	43	2	17	2	32	7	2	2	3
Average	6	6		7		2		3		34		11		47		14		3

*U = Unbeaded
**B = Beaded

TABLE II

COMPLETE HIGHWAY TEST DATA AT 2 MONTHS

Paint Type	Butadiene/Vinyl Toluene		Ga. Spec.		Lacquer		Amine Epoxy		Straight Alkyd		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
	A. Highway Test Film Integrity																	
Concrete																		
10 mils	1	2	4	4	2	2	-	-	5	5	9	8	4	4	6	6	8	8
15 mils	6	6	7	7	4	4	-	-	8	8	9	9	4	4	6	6	9	9
20 mils	8	8	8	8	5	5	-	-	9	9	9	9	4	4	6	6	9	9
Average	5	5	6	6	4	4	-	-	7	7	9	9	4	4	6	6	9	9
Asphalt																		
10 mils	3	3	6	6	3	3	6	4	6	6	5	5	2	4	5	5	6	6
15 mils	6	6	7	7	4	4	6	6	7	7	7	7	2	3	5	5	7	7
20 mils	7	7	7	7	4	4	-	-	7	7	8	8	2	4	5	5	8	8
Average	5	5	7	7	4	4	6	5	7	7	7	7	2	4	5	5	7	7
	B. Highway Night Visibility Test																	
	(Data not obtained)																	

*U = Unbeaded
**B = Beaded

TABLE III

COMPLETE HIGHWAY TEST DATA AT 3 MONTHS

Paint Type	Butadiene/Vinyl Toluene		Ga. Spec.		Lacquer		Amine Epoxy		Straight Alkyd		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
A. Highway Test Film Integrity																		
Concrete																		
10 mils	1	2	4	4	1	1	-	-	4	4	8	8	6	6	6	6	7	8
15 mils	5	5	5	5	1	1	-	-	7	7	8	8	4	8	6	6	8	8
20 mils	7	7	7	7	1	1	-	-	8	8	9	9	4	7	6	6	9	9
Average	4	5	5	5	1	1	-	-	6	6	8	8	5	7	6	6	8	8
Asphalt																		
10 mils	3	3	4	4	3	3	4	3	6	6	5	5	2	3	5	5	6	6
15 mils	5	5	6	6	4	4	4	4	7	7	6	6	2	2	5	5	8	8
20 mils	7	7	7	7	4	4	-	-	7	7	7	8	2	2	5	5	8	8
Average	5	5	6	6	4	4	4	4	7	7	6	6	2	2	5	5	8	8
B. Highway Night Visibility Test																		
Concrete																		
10 mils	2	3	2	4	2	3	-	-	4	10	3	7	5	33	3	43	7	7
15 mils	4	4	2	2	3	2	-	-	5	25	2	8	4	32	4	6	7	7
20 mils	4	5	3	3	3	2	-	-	5	8	2	15	3	45	7	24	7	7
Average		4		3		2				14		10		37		24		7
Asphalt																		
10 mils	2	2	2	3	2	2	2	2	2	15	2	5	2	17	7	14	3	3
15 mils	5	5	2	3	3	2	2	2	2	17	2	3	2	21	6	4	3	4
20 mils	6	6	2	3	2	3	-	-	2	17	2	5	1	17	3	3	3	3
Average		4		3		2		2		16		4		18		7		3

*U = Unbeaded
**B = Beaded

TABLE IV

COMPLETE HIGHWAY TEST DATA AT 5 MONTHS

Paint Type	Butadiene/Vinyl Toluene		Ga. Spec.		Lacquer		Amine Epoxy		Straight Alkyd		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
									A. Highway Test Film Integrity									
Concrete																		
10 mils	0	1	2	2	0	0	-	-	3	3	7	8	5	5	6	6	5	7
15 mils	4	4	3	4	0	0	-	-	6	6	8	8	3	5	6	6	7	7
20 mils	4	5	5	5	1	1	-	-	7	7	8	9	3	5	6	6	7	7
Average	3	3	3	4	0	0	-	-	5	5	8	8	4	5	6	6	6	7
Asphalt																		
10 mils	1	1	3	3	2	2	4	3	6	6	4	4	2	3	5	5	5	4
15 mils	4	4	4	4	4	4	4	5	6	6	5	5	2	2	5	4	6	6
20 mils	7	7	5	5	4	4	-	-	6	7	6	6	2	2	5	4	7	7
Average	4	4	4	4	3	3	4	4	6	6	5	5	2	2	5	4	6	6
									B. Highway Night Visibility Test									
Concrete																		
10 mils	1	2	2	2	2	2	-	-	3	6	3	7	5	30	4	50	6	7
15 mils	2	3	1	2	2	2	-	-	5	23	3	8	4	38	4	9	10	10
20 mils	3	3	2	2	2	2	-	-	5	6	3	11	6	47	8	31	10	10
Average		3		2		2				12		9		38		30		9
Asphalt																		
10 mils	2	1	1	1	1	1	2	2	3	14	3	3	1	6	5	19	3	3
15 mils	3	2	1	1	2	2	2	2	3	15	2	2	2	18	7	5	3	3
20 mils	4	4	1	1	2	3	-	-	3	17	2	4	2	19	3	2	3	4
Average		2		1		2		2		15		3		14		9		3

*U = Unbeaded
**B = Beaded

TABLE V

COMPLETE HIGHWAY TEST DATA AT 7 MONTHS

Paint Type	Butadiene/Vinyl Toluene		Ga. Spec.		Lacquer		Amine Epoxy		Straight Alkyd		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
						A. Highway Test Film Integrity												
Concrete																		
10 mils	0	0	1	1	0	0	-	-	2	3	7	8	3	5	6	6	5	6
15 mils	2	2	2	3	0	0	-	-	5	6	8	8	3	5	6	6	7	7
20 mils	3	3	3	3	0	0	-	-	7	7	8	8	3	5	6	6	7	7
Average	2	2	2	2	0	0	-	-	5	5	8	8	3	5	6	6	6	7
Asphalt																		
10 mils	0	0	1	3	1	1	4	3	6	6	5	5	2	3	6	5	4	4
15 mils	3	3	4	4	2	2	4	5	6	6	6	6	2	2	5	5	6	6
20 mils	5	5	5	5	3	3	-	-	6	6	7	7	2	2	5	5	6	6
Average	3	3	3	4	2	2	4	4	6	6	6	6	2	2	5	5	5	5
						B. Highway Night Visibility Test												
Concrete																		
10 mils									4	5	4	8	4	28	3	36	6	7
15 mils									6	16	5	8	6	34	5	15	9	8
20 mils									7	9	4	10	6	42	10	34	10	9
Average										10		9		35		28		8
Asphalt																		
10 mils							2	2	3	11	2	3	2	3	6	9	3	3
15 mils							3	3	2	13	3	2	2	13	3	3	3	3
20 mils							-	-	3	13	2	4	2	11	3	2	6	4
Average							3	3		13		3		9		5		

*U = Unbeaded
**B = Beaded

TABLE VI

COMPLETE HIGHWAY TEST DATA AT 9 MONTHS

Paint Type	Butadiene/Vinyl Toluene		Ga. Spec.		Lacquer		Amine Epoxy		Straight Alkyd		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
A. Highway Test Film Integrity																		
Concrete																		
10 mils	0	0	0	0	0	0	-	-	2	3	6	6	2	3	7	7	3	3
15 mils	1	1	0	1	0	0	-	-	5	5	6	6	1	3	7	6	4	4
20 mils	2	2	2	2	0	0	-	-	6	6	5	8	2	4	7	7	6	6
Average	1	1	1	1	0	0	-	-	4	5	6	7	2	3	7	7	4	4
Asphalt																		
10 mils	0	0	1	2	1	1	4	4	5	5	5	5	3	2	5	5	2	2
15 mils	2	2	3	3	2	3	4	4	5	5	6	5	3	3	5	5	4	4
20 mils	4	4	3	3	3	3	-	-	5	6	6	5	3	3	5	4	4	4
Average	2	2	2	3	2	2	4	4	5	5	6	5	3	3	5	5	3	3
B. Highway Night Visibility Test																		
Concrete																		
10 mils									4	6	4	6	7	27	10	6	15	12
15 mils									7	14	5	6	7	20	4	15	9	7
20 mils									6	6	4	10	4	35	16	22	11	9
Average										9		7		27		14	12	9
Asphalt																		
10 mils							2	1	4	7	8	10	7	6	4	12	2	2
15 mils							2	2	9	10	3	2	9	11	3	2	2	3
20 mils							-	-	9	9	1	3	7	8	12	8	2	3
Average								1		9		5		8		7		3

*U = Unbeaded
**B = Beaded

TABLE VII

COMPLETE HIGHWAY TEST DATA AT 12 MONTHS

Paint Type	Butadiene/Vinyl Toluene		Ga. Spec.		Lacquer		Amine Epoxy		Straight Alkyd		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
						A. Highway Test Film Integrity												
Concrete																		
10 mils	0	0	0	0	0	0	-	-	0	1	4	5	1	1	5	5	0	0
15 mils	0	0	0	0	0	0	-	-	5	6	6	7	1	1	5	4	1	1
20 mils	0	0	1	1	0	0	-	-	5	5	7	8	1	2	6	6	3	3
Average	0	0	0	0	0	0	-	-	3	4	6	7	1	1	5	5	1	1
						B. Highway Night Visibility Test												
Concrete																		
10 mils									2	3	2	3	3	11	3	15	4	3
15 mils									3	7	2	4	2	11	3	2	4	5
20 mils									3	3	2	3	2	25	4	19	8	6
Average										4		3		18		12		5

*U = Unbeaded
**B = Beaded

TABLE VIII

COMPLETE HIGHWAY TEST DATA AT 18 MONTHS

Paint Type	Butadiene/Vinyl Toluene		Ga. Spec.		Lacquer		Amine Epoxy		Straight Alkyd		Chlor. Rubber Alkyd		Urethane		Amide Epoxy		Amine Adduct Epoxy	
Paint Number	6		11		13		14		15		16		17		18		19	
	U*	B**	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
A. Highway Test Film Integrity																		
Concrete																		
10 mils									0	0	0	0						
15 mils									1	1	2	2						
20 mils									0	1	2	4						
Average									0	1	1	2						
B. Highway Night Visibility Test																		
(Data not obtained)																		

*U = Unbeaded
**B = Beaded

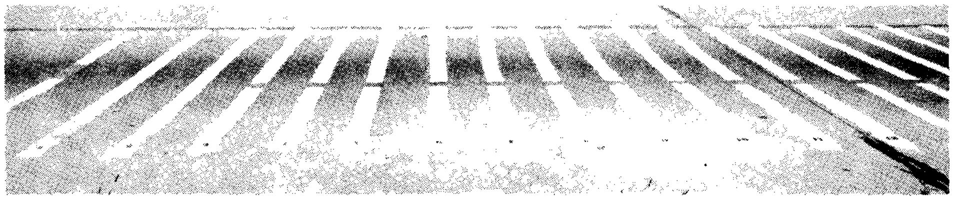
D. Photographs of Stripes

Paint No. 6

Concrete: Stripes 1-6
Asphalt: Stripes 49-54

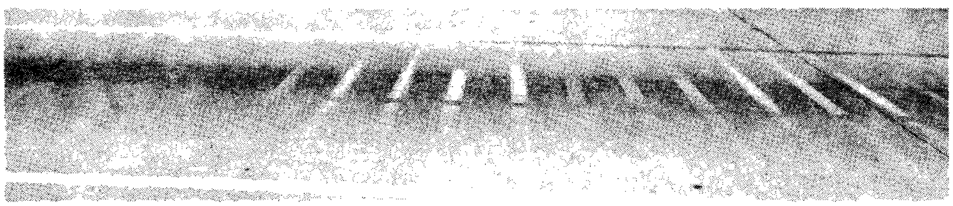
Paint No. 11

Concrete: Stripes 7-12
Asphalt: Stripes 55-60

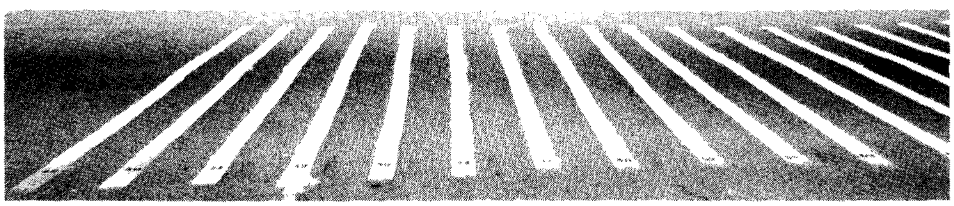


Concrete, Initial

Concrete, 9 Months



Concrete, 12 Months



Asphalt, Initial

Asphalt, 9 Months

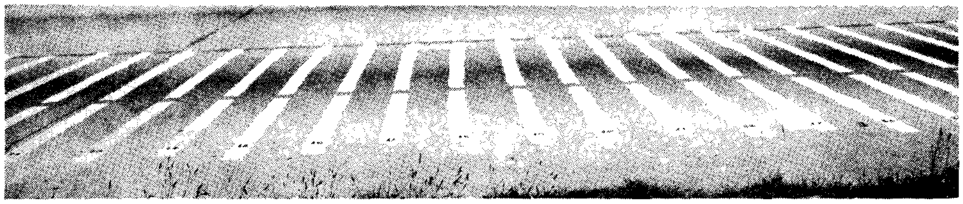
Figure 16. Weathering of Paints No. 6 and 11.

Paint No. 13

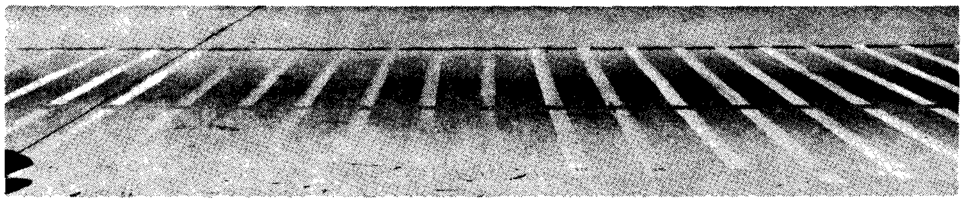
Concrete: Stripes No. 13-18
Asphalt: Stripes No. 61-66

Paint No. 15

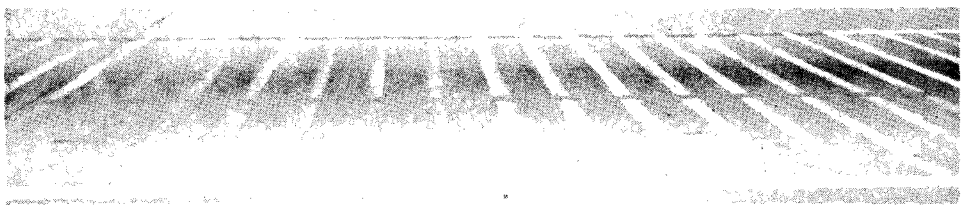
Concrete: Stripes No. 19-24
Asphalt: Stripes No. 67-72



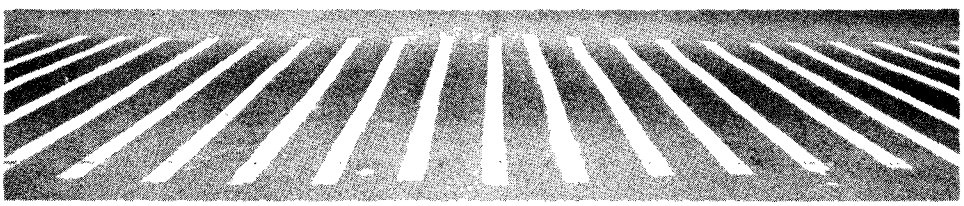
Concrete, Initial



Concrete, 9 Months



Concrete, 12 Months



Asphalt, Initial

Asphalt, 9 Months

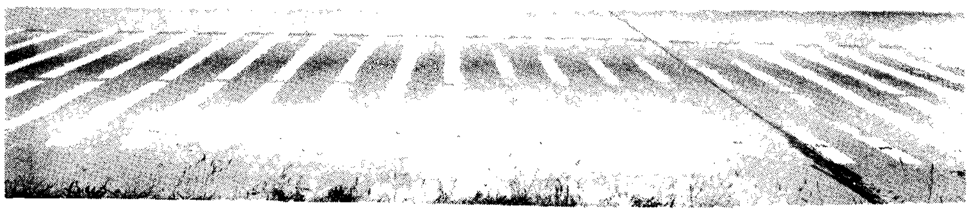
Figure 17. Weathering of Paints No. 13 and 15.

Paint No. 16

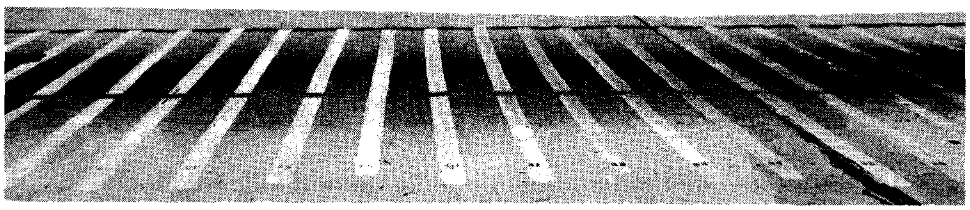
Concrete: Stripes No. 25-30
Asphalt: Stripes No. 73-78

Paint No. 18

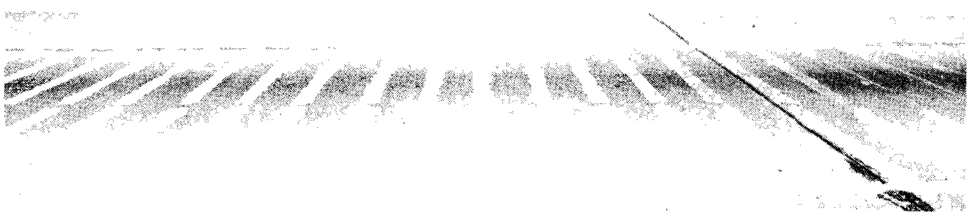
Concrete: Stripes No. 31-36
Asphalt: Stripes No. 79-84



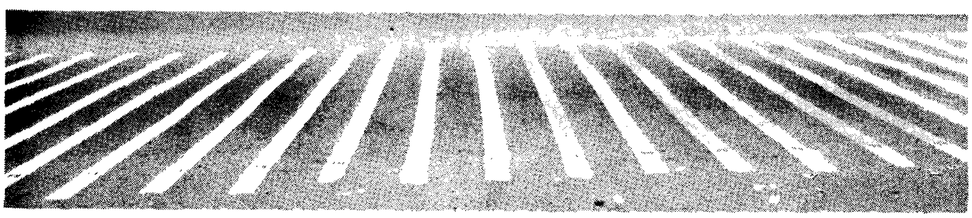
Concrete, Initial



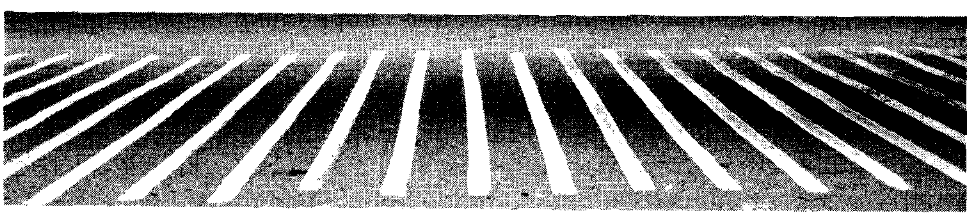
Concrete, 9 Months



Concrete, 12 Months



Asphalt, Initial



Asphalt, 9 Months

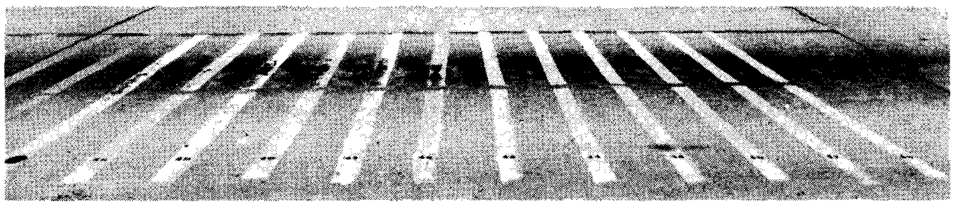
Figure 18. Weathering of Paints No. 16 and 18.

Paint No. 17

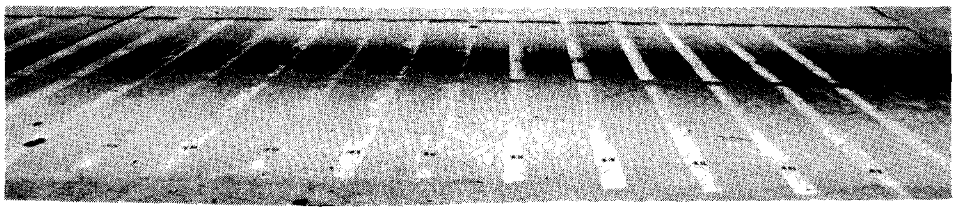
Concrete: Stripes No. 37-42
Asphalt: Stripes No. 85-90

Paint No. 19

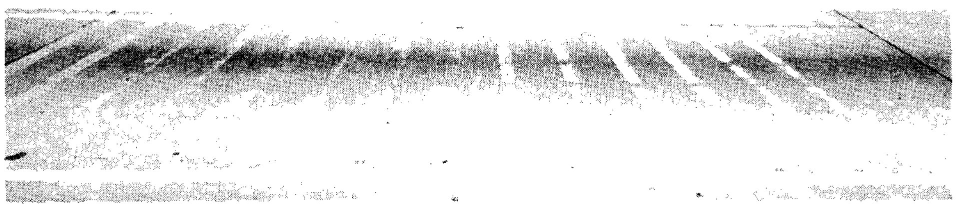
Concrete: Stripes No. 43-48
Asphalt: Stripes No. 95-100



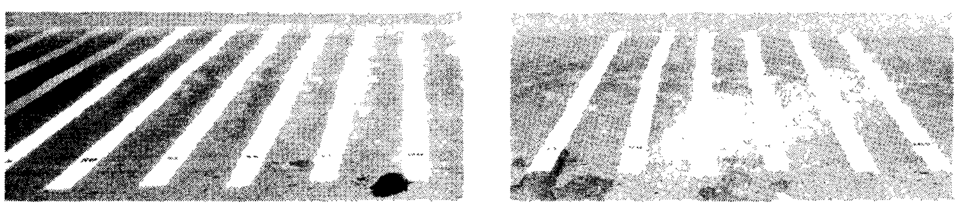
Concrete, Initial



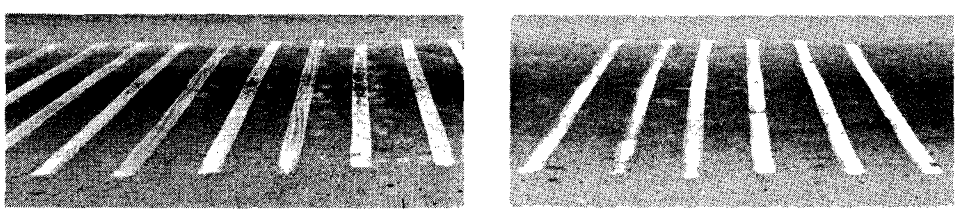
Concrete, 9 Months



Concrete, 12 Months



Asphalt, Initial



Asphalt, 9 Months

Figure 19. Weathering of Paints No. 17 and 19.

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia

FINAL TECHNICAL REPORT

Georgia Tech Project B-210

Research Project HPS-1(60)

USE OF RADIOISOTOPES IN DEVELOPMENT OF TEST METHODS AND FORMULATIONS FOR TRAFFIC PAINTS

By

W. R. TOOKE, JR. and W. H. BURROWS

PART II

HIGHWAY CROSS-STRIPE TESTS OF TRAFFIC PAINTS SERIES II AND III

September 30, 1965

Prepared for
STATE HIGHWAY DEPARTMENT OF GEORGIA

in cooperation with
U. S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

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I. INTRODUCTION

Of the four original objectives (see Foreword, Part I), two remained of paramount importance:

1. Development of laboratory wear tests that can be correlated with the actual wear of traffic paints in highway use.

2. Formulation of traffic paints, utilizing the devices and findings of the foregoing studies, as a guide to improve performance.

The accelerated wear tester and procedure had been subjected to a number of modifications in construction, mode of operation, preparation of test panels, etc. These are described in detail in Part III of this report. This part (Part II) is concerned with the formulation and application of paints for highway cross stripe testing and the accumulation of additional data for correlation purposes.

In Test Series II emphasis was given to improved beading technique, to assessment of the reproducibility of tests, to modifications of formulations, and to the correlation of laboratory and highway results. By the time this series was well under way, the rate and mode of failure had indicated the presence of parameters not previously reckoned with. It was also becoming increasingly clear that laboratory wear testing results would become meaningful only through a lengthy developmental and correlation study. Thus, to accomplish further reliable formulation advancement, additional highway studies would be required. Series III is, therefore, primarily a study of formulations with special interest directed to "bead in" compositions and with continuing attention also to the questions of reproducibility and correlation. The sections that follow describe these two series in detail.

II. HIGHWAY TEST SERIES II

A. Plan of Investigation

This series of tests was primarily intended to evaluate modifications in formulations selected from those previously tested in Series I. These modifications were developed to correct certain defects observed in the earlier tests. Additional objectives of this series were: (1) to assess the reproducibility of test conditions by replicating the control paint exposure, (2) to attain more representative beading of test stripes, and (3) to accumulate additional data for correlation with laboratory tests.

The experience gained in the Series I tests provided certain guidelines for the planning of Series II:

1. Beading had been unsatisfactory in Series I, making further studies in this direction necessary. Unbeaded paints appeared to be of no practical interest; consequently, this series would be confined to beaded stripes.

2. Since film thickness had definitely been shown to be a factor in paint durability, it was desirable to continue the practice of applying at three film thicknesses.

3. Comparative results between asphalt and concrete were adequately predictable; consequently, this series would be confined to concrete as a substrate.

On the basis of the foregoing considerations the test design consisted of:

1. Five selected formulations
2. All applied to concrete only
3. At 10, 15, and 20 mils wet thickness
4. With all applications beaded

Thus the test series required

$$5 \times 1 \times 3 \times 1 = 15 \text{ stripes}$$

B. Paints, Preparation, and Application

Complete formulation data sheets on each test paint are included in Appendix A. For reference in the following discussions, the paints of this series are identified as follows:

Paint No.	Vehicle Type
15	Alkyd, linseed, 30% phthalic
29	Alkyd, minimum Ga. Specs. (similar to No. 15)
36	Chlorinated rubber modified alkyd, 50% PVC
37	Epoxy - polyamide (lacquer drying)
38	Epoxy - amine adduct

Formulation No. 15 is a "control" paint, identical with the same item in Series I. No. 29 is representative of the quality that may be furnished by vendors to meet Georgia Highway Department Tentative Maintenance Specification No. 4. No. 36 is an approach to further improvement in the formulation of the chlorinated rubber modified type (No. 16) studied in Series I. No. 37 is a major revision in the epoxy-polyamide studied in Series I. The earlier formulation (No. 18) depended upon resin reaction to achieve initial drying; the new formulation is of a lacquer-drying type. Formulation No. 38 is a slight modification of No. 19 from Series I.

It was not feasible to include in this series several items that were originally felt to be of interest. A moisture-curing polyurethane formulation could not be included because of very poor can stability. Attempts to achieve a satisfactory hot melt composition based on plasticized sulfur were not advanced sufficiently to justify field testing. These and other studies of new materials were continued in the laboratory.

All paints were prepared by grinding in a one-gallon pebble mill to a minimum texture of Hegman 3.

On September 3, 1963, highway cross-stripes were applied to the concrete roadway of Interstate 85 in the outer northbound lane near the Lenox Road bridge immediately south of the Series I stripes. The equipment and procedures were similar to the Series I applications except that the beading device was attached directly to the frame of the paint spray machine so that beading was applied immediately behind the spraying operation. The beading rate was the same as in Series I; 6 pounds per gallon of paint. All formulations exhibited satisfactory application properties.

C. Performance Observations

Evaluations of performance were based on the following ASTM testing procedures:

D821-47	Abrasion, Erosion Resistance
D913-51	Chipping Resistance
D1011-52	Night Visibility

Chipping was the only mode of paint failure observed in this series; thus, all the tabulations of "integrity" refer to chipping exclusively.

Observations of integrity and night visibility at weathering periods of one, three, and six months are presented in Appendix B, Table II. Photographs of the test stripes made initially and at three and six months are shown in Appendix C, Figures 7, 8, 9, 10, and 11.

D. Discussion of Results

Integrity and night visibility of the cross stripes of Series II drastically deteriorated over the winter months and at 6 months film integrity was in the range of 1 to 3 for the group. Performance profiles for integrity and night visibility are plotted in Figure 1. Note that surprisingly little difference in performance is shown among the group after six months exposure. It is believed that hard winter may have contributed to the comparatively short life of the paints. The use of chains on cars on snowy and icy days, an unusual practice in this section, greatly decreased the life of the paint during winter months. At three months exposure, however, prior to the severe winter conditions, differences in the performance of these paints were well developed. The superior performance of thicker films is clearly demonstrated by Figure 2. Both night visibility and integrity show a positive response to increased film thickness for most of the paints.

E. Conclusions

1. Comparisons of Paint No. 15 in Series I with Series II indicate that a given paint may exhibit different modes and rates of failure upon replications of tests over time intervals.

2. The relative rates of deterioration of various paints change with the severity of weathering and wear conditions. Thus, early observations of wear may not provide a reliable indication of ultimate performance.

3. The improvement of paint integrity and night visibility with increased film thickness up to 20 mils wet was further confirmed.

4. No really significant performance superiority was demonstrated for any of the special formulations as compared with the conventional alkyd type.

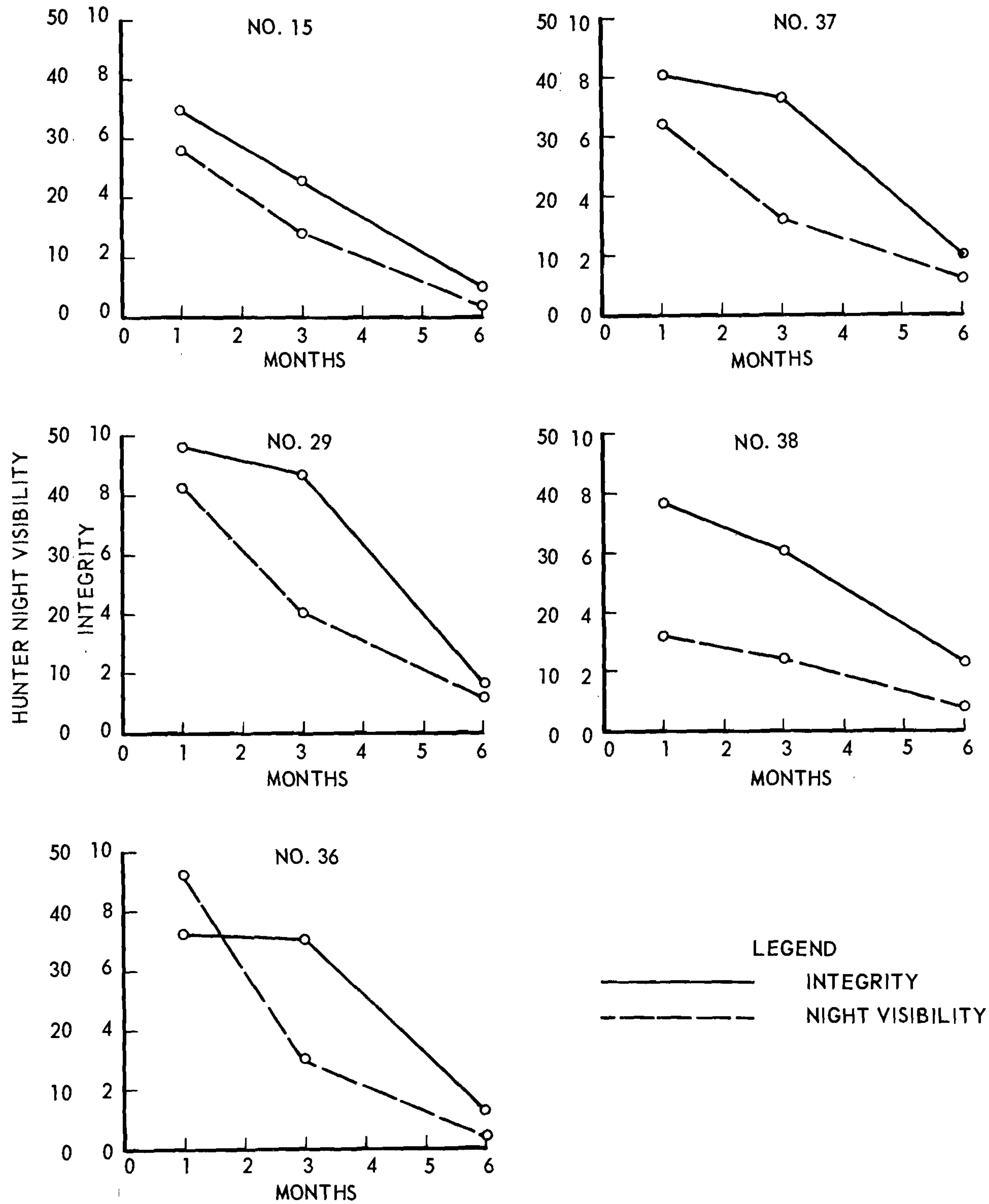

Figure 1. Performance Profiles, Highway Test Series II.

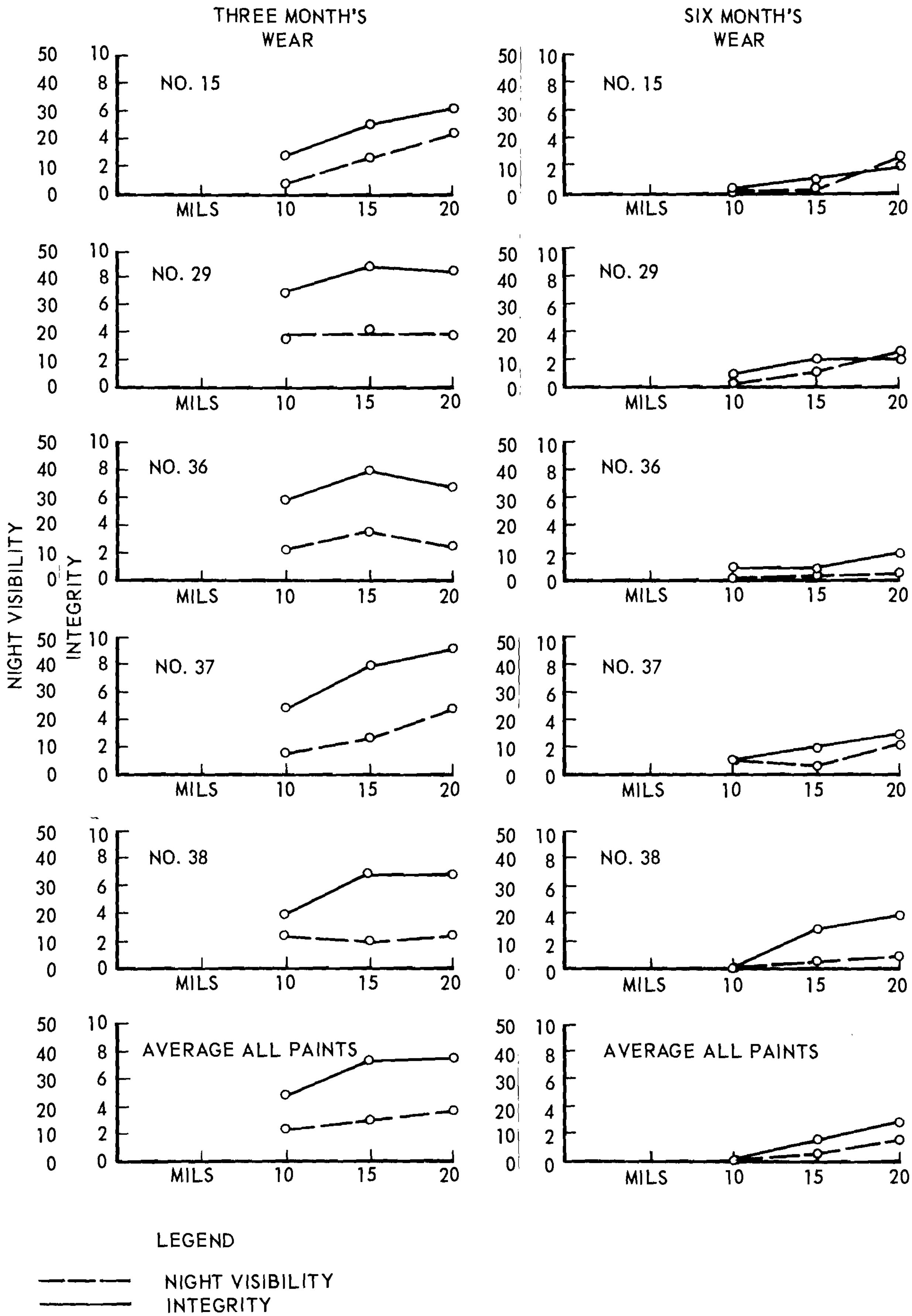

Figure 2. Integrity and Night Visibility versus Film Thickness, Highway Series II

III. HIGHWAY TEST SERIES III

A. Plan of Investigation

Findings of the Series I and II highway studies and of the laboratory wear test program indicated a need for a third series of highway tests. Traffic paints had been observed to vary appreciably, in both rate and mode of failure, when exposed at different times on the same highway test site. This effect involved parameters not previously recognized, and further investigation appeared necessary. Developmental work on the laboratory wear tester required reliable correlation guidance which did not appear to be available from the two previous highway series. Moreover, the limitations of the accelerated wear tester in approaching dynamic similitude with highway conditions were fully appreciated by the time those series were complete. The wear tester was clearly inadequate at that time for reliable evaluations of high-performance paints and the previous highway tests had raised further questions about interpretation of field results. Additional field testing would fill gaps in both correlation and evaluation of new formulations.

On behalf of improved correlation, the control alkyd, the Parlon-alkyd, and the Pliolite type paints were selected for retesting. New work included an application of the control alkyd in two coats, evaluation of an epoxy ester based paint, and a study of "beads-in" formulations.

The two-coat study had been suggested by representatives of the Bureau of Public Roads, and both previous test series had indicated that thicker films yield enhanced durability.

The epoxy ester study involved vehicle synthesis work based on the premise that this vehicle can be designed to produce an enhancement in important physical properties, as compared with the ordinary alkyd, and yet retain most if not all of the desirable characteristics of the alkyd.

"Beads-in" traffic paints are the subject of several patents, and have been investigated and reported favorably in the literature*. Laboratory studies with the accelerated wear tester appeared to confirm the merits of "bead-in" formulations and warranted an extensive evaluation in the new series.

The specific plan of investigation for Highway Test Series III utilized the following four paint types:

Paint No. 90	Standard alkyd
Paint No. 88	Epoxy ester
Paint No. 84	Chlorinated rubber-alkyd
Paint No. 86	Butadiene/vinyl toluene

Each was applied to concrete only, with and without "bead on" treatment, and at wet film thicknesses of 10, 15, and 20 mils. In addition, these paint formulations were modified (Paints No. 91, 89, 85, and 87) to incorporate a constant volume of glass beads, and were applied to concrete only, with and without "bead on" treatment at wet film thicknesses of 20 and 30 mils. Finally, a single two coat application of the control paint (no beads in) was applied. Each coat of this application was beaded in the normal manner with a 20 minute interval between coats. The foregoing description of the program may be further clarified by reference to Appendix B, Table III. The number of test stripes involved is accounted for as follows:

<u>Plain Paints</u>

Paints x Beading - No Beads x Thicknesses

4 x 2 x 3 = 24

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*Minor, Carl E. and Cody, Lowery W., "Application of Plain and Beaded Traffic Paints," Highway Research Board, Bulletin No. 57, pp. 71-76, 1952.

"Bead-In" Paints

Paints x Beading - No Beads x Thicknesses							
4	x	2	x	2		=	16
Double Stripes							1
					Total Stripes		41

B. Paints, Preparation, and Application

1. Epoxy Ester Synthesis

Alkyd varnishes have exhibited good performance as traffic paint vehicles and should be an appropriate starting point for further improvements in performance. The objective would be to enhance toughness, water resistance, and adhesion without losing other desirable properties. Epoxy esters appear to be capable of meeting these requirements. In effect, the glycerol phthalate backbone of the alkyd would be replaced with epoxy resin, while the fatty acid portions of the molecule would remain relatively unchanged.

An epoxy ester of this type was synthesized in the laboratory. Traffic paint prepared from this vehicle was observed to have similar characteristics to the alkyd paint, but with a slight increase in film hardness. Preliminary tests on the accelerated wear tester indicated a probable superiority of the new paint as compared with the alkyd type.

The epoxy ester vehicle utilized for field testing in Paints No. 88 and 89 was prepared as follows:

EPOXY ESTER LX-1

Material	Batch Quantity, g.	% by Weight
Linseed Fatty Acids (ADM # 505)	540	56.3
Epon 1004 (Shell Chemical Co.)	420	43.7
Sodium Benzoate	0.54	0.056

All materials were charged to a 3 neck flask equipped with agitator, reflux condenser and inert gas inlet. Ten grams of VM&P naphtha was added for reflux, and the batch was cooked under nitrogen for 3 hours to a final temperature of 500° F. The batch was cooled and thinned to 55% solids with VM&P naphtha.

VARNISH CONSTANTS

Acid No.	11.0
Viscosity (Gardner)	L
Density (lbs/gal)	7.35
Non Volatile (per cent)	55
Solvent	VM&P naphtha

2. Paint Preparation

Paint formulation data are detailed in Appendix A. All paints were prepared in a high speed blendor and dispersed to a minimum texture of Hegman 3. The "bead-in" paints were prepared by adding appropriate quantities of fine glass beads (3M Type #103-5005) and additional thinners to the corresponding unbeaded formulations.

The proper level of loading with glass beads was determined from prior experimental work utilizing the laboratory wear tester. A parameter analogous to pigment volume concentration (PVC) was used to characterize the bead loading of a formulation:

$$\text{Bead Volume Concentration (BVC), \%} = \frac{\text{Volume of Beads x 100}}{\text{Volume of Beads + Pigment Volume + Non-Volatile Vehicle Volume}}$$

At the selected bead volume concentration of approximately 45%, it will be observed that where consistencies are adjusted to approximately original values with added thinner, the volume solids content of the paints are increased.

3. Paint Application

On November 12, 1964, highway cross-stripes were applied to the concrete roadway of Interstate 85 in the outer northbound lane approximately 0.6 miles south of the Lenox Road bridge. Equipment and procedures were similar to Series II except that the spray gun nozzle was changed from a Binks No. 68PB (external mixing) to a Binks No. 709 (internal mixing) type. The latter provided improved uniformity of pattern with both beaded and unbeaded formulations. Application properties were satisfactory with all formulations.

C. Performance Observations

Evaluation methods were identical with Series II tests; however, since some cases of abrasive modes of failure were observed in the present series, integrity failures have been identified by type (abrasion, chipping).

Observations of integrity and night visibility at weathering periods of 0, 3, 9, 10*, and 17 weeks are presented in Appendix B, Tables III,

*The 10 week observations were made after a heavy ice storm, and are limited to integrity only.

IV, V, VI, and VII. Photographs of the test strips initially and at 17 weeks are shown in Appendix C, Figures 12 through 19.

D. Discussion of Results

1. Relative Paint Performance

The test results for the various "bead on" paint formulations have been summarized in two plots. Figure 3 shows integrity and night visibility of each paint as a function of the service period. Perhaps the most distinguishing feature of this study is the general similarity of results for the several paints studied. Paint #86 (Pliolite VT) was slightly poorer in integrity, definitely poorer in bead retention and showed a tendency to darken or stain. The performances of Paints #84, 88, and 90 were very similar except that Paint #88 (epoxy ester) showed some tendency for slow dry (slight traffic smears). Particular attention is directed to a double coat application of Paint #90 (alkyd). The enhanced durability of this two coat (15 mils + beads each coat) application was clearly outstanding.

2. Bead On and Bead In Effects

The effect of "bead on" beading in enhancing paint integrity was demonstrated for all paints except No. 86. Comparisons of average test observations of plain (0% BVC) and "bead-in" (45% BVC) paints are shown in Figure 4. The enhancement was less pronounced for the "bead in" paints. The "bead in" paints did not display significantly superior integrity as compared with the plain paints; however, they did maintain night visibility at uniformly higher levels.

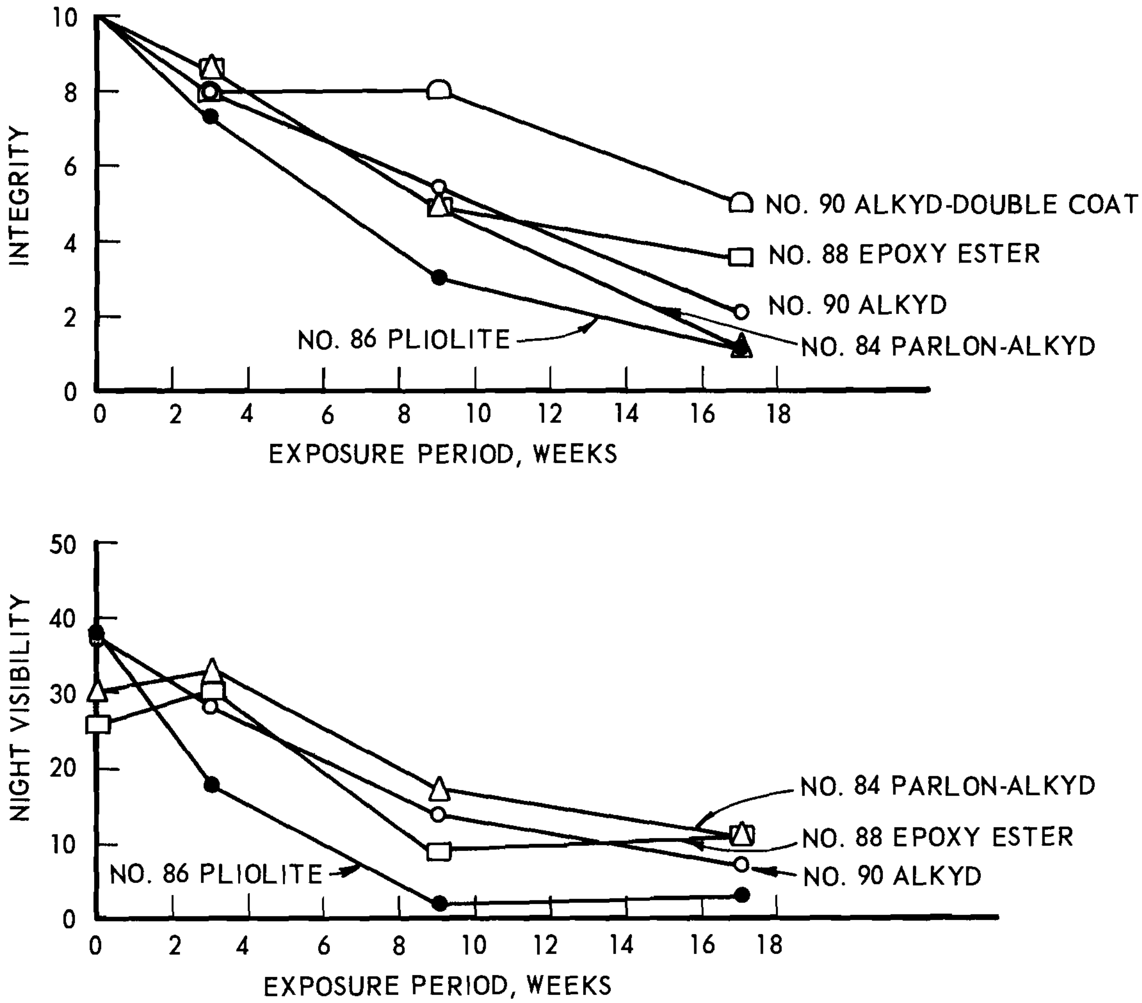


Figure 3. Integrity and Night Visibility versus Exposure Time. Average Value for "Plain" 10, 15, and 20 mil Films, Series III.

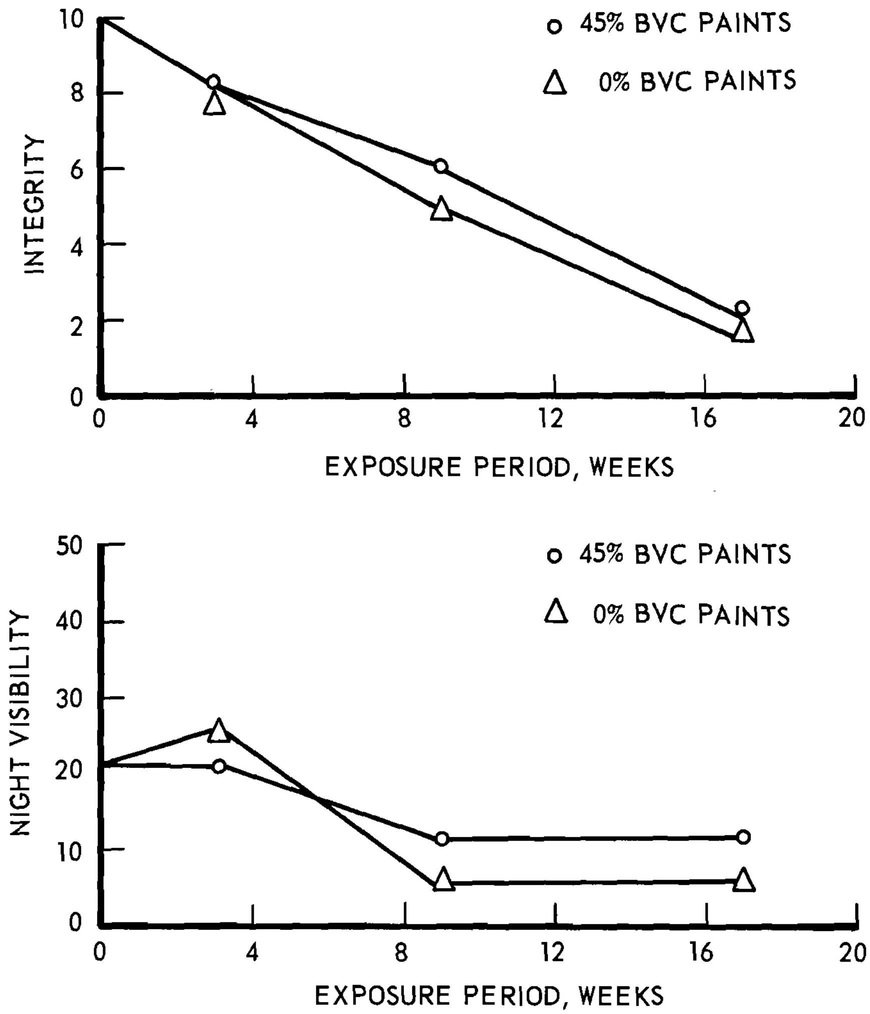


Figure 4. Comparison of "Plain" (0% BVC) versus "Bead-in" (45% BVC) Paints, Series III.

3. Film Thickness

Average test observations for all "bead-on" paints are presented as a function of film thickness in Figure 5. The data clearly show enhanced integrity and night visibility with increasing film thickness of "bead on" paints at 0% BVC. Among the "bead in" paints (45% BVC) at 20 and 30 mils, the thickness effect was negligible.

4. Effect of Concrete Surface Condition

The rate of attrition of the control paints was definitely greater than in Series I or II, and chipping became the overwhelmingly predominant mode of failure. These changes are attributed primarily to differences in the texture, degree of contamination, and wear condition of the concrete roadway at the several test sites. The effect of all other experimental and environmental factors are not considered sufficient to account for the observed differences. Under these circumstances, for good quality paints, erosion resistance becomes irrelevant, and performance is primarily dependent upon adhesion.

5. Environmental Extremes

The observations made at 10 weeks, following an ice storm and use of tire chains on the roadway, were intended to assay the immediate effects of such environmental extremes. The condition of the test stripes of all paints without the "bead in" modification was not significantly different from the week before despite the intervening ice storm, although slightly more deterioration was observed with the "bead in" paints. It should be noted that film failures were already well developed by this time, and immediate effect would be less apparent than on new stripes; nevertheless, the small changes in appearance were surprising.

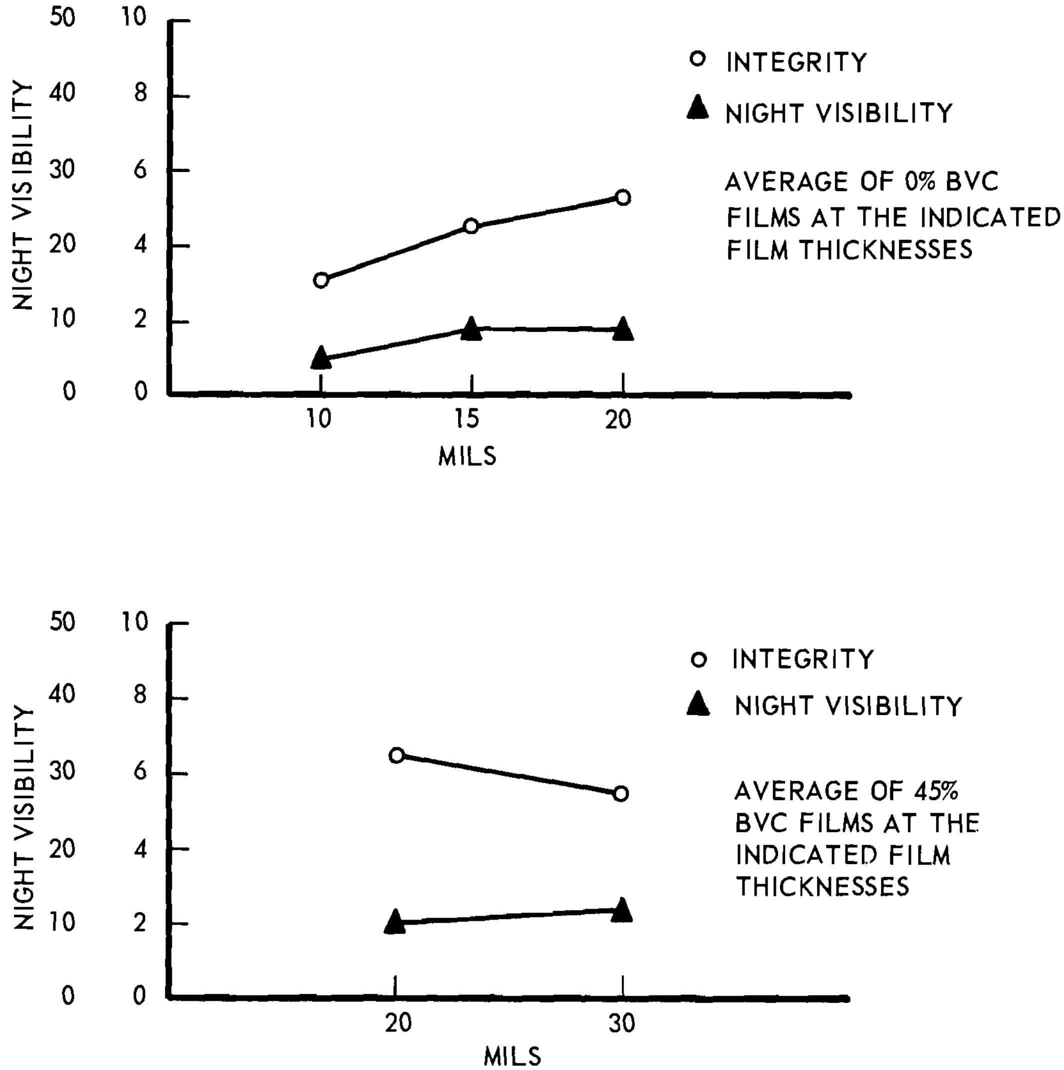


Figure 5. Average Film Thickness Effects at Nine Weeks Exposure, Series III.

E. Conclusions

The foregoing observations are summarized as follows:

1. Series III exhibited higher wearing rates than previous series.

2. No large extremes in relative paint performance were observed, but a two-coat system was outstanding.

3. "Bead on" beading enhances paint durability.

4. "Bead in" paints were significantly superior to plain "bead on" paints only in night visibility retention.

5. A general enhancement of performance with increased film thickness was again demonstrated.

6. An ice storm produced no immediate catastrophic paint failure.

IV. GENERAL SUMMARY OF HIGHWAY TEST FINDINGS

Performance data, results and conclusions have been reported on three individual series of highway tests. Series I was reported as Part I of the final report; Part II (this part) covers Series II and III. This summary is not intended to survey comprehensively all of the previous discussions of results, but rather to abstract the more significant results and to interpret the findings as a whole. The following discussion is organized under headings of the several dependent variables of interest.

A. Substrate Type

Comparisons of portland cement (P/C) concrete versus asphaltic concrete substrates were investigated only in Series I. Paints of poor durability exhibited very similar performance on both substrates but were possibly slightly better on asphalt. Paints of good durability generally exhibited better performance on P/C concrete than on asphalt. The results suggest that the durability of the best paints on asphalt may be limited by the relative instability of this substrate. P/C concrete is seen to be a better substrate for testing durable paints. Although the ordering of results is similar, a better performance spread is provided by the P/C concrete substrate.

B. Film Thickness

The film thickness variable was designed into all three series of cross stripe studies, and the results were consistent and conclusive.

In Series I, where erosive failure modes predominated, a definite positive correlation of film integrity with film thickness was observed. Because of poor beading of much of this series, it was not possible to demonstrate that this integrity relationship would be valid for all properly beaded films, or that a positive correlation of film thickness would apply to night visibility properties of all paints tested. Nevertheless, positive correlations were observed for all valid tests.

In Series II, with chipping the predominant mode of failure and with all films beaded, a definite positive correlation of both integrity and night visibility with film thickness was observed.

In Series III, with chipping failures predominating, beaded films again displayed positive correlation of integrity and night visibility with film thickness. Results for unbeaded films were inconclusive in this series. Very rapid loss of adhesion and the resulting heavy chipping of unbeaded films apparently precluded observation of a thickness effect.

Thus it has been shown consistently that the integrity of beaded films is dependent upon film thickness under chipping conditions, and probably also for erosive conditions. In the latter case, judgment must be reserved in the light of limited test results; however, it is only logical to deduce that thicker films will erode more slowly. Composite results of the three series demonstrate that overall performance of highway cross stripes improves directly with increasing wet film thickness up to levels of 20 mils. Wet film thicknesses of 10 mils are generally incapable of properly binding drop-on beading.

Some speculation about film thicknesses beyond 20 mils may be indulged, particularly since a two coat 30 mil film was included in Series III. The relatively superior performance of this two-coat film suggests that 20 mils is not an upper limit, provided however, that adequate drying can be achieved. For single coat applications, it is believed that 20 mils may approach the practical limit of the type of paints investigated in the program.

C. "Bead-On" Beading

Data from Series I and III clearly demonstrated that for paints which retain beads properly, beading enhances paint integrity (erosive or chipping modes) as well as providing night visibility. At the outset of this program the importance of a technique to assure controlled beading was not properly appreciated. Improvements were embodied in Series II and III, and even further improvements would be desirable, as night visibility may well be regarded as the primary performance criterion of traffic paint. Bead application technique affects both initial and subsequent (weathered) observations of night visibility. Thus, the important bead bonding characteristics of a formulation cannot be properly evaluated unless the beading is uniform.

D. Formulation Study - "Beads In"

This study was undertaken in Series III only. Bead-in paints demonstrated an ability to retain night visibility at uniformly higher levels than corresponding "bead-on only" paints. The anticipated superior durability of the bead-in paints did not materialize. Laboratory evaluation work which preceded these field tests was subject to limitations that have subsequently become acutely apparent. Further formulation work with bead-in paints is definitely warranted. Were further improvements in durability to be realized, the need for better night visibility retention would become more critical; this need might best be met through the bead-in formulations.

E. Formulation Study - Vehicles

Formulation details have been discussed in connection with each of the test series. In one sense, the findings have been discouraging.

The novel vehicle types, which have exhibited outstanding performance in other applications, fell short of expectations. This is not to say that the novel vehicles produced inferior paints, but rather than the superiorities indicated in laboratory testing were not fully confirmed in the field. Again, the limitations of laboratory testing inhibited formulation development. Development of a laboratory testing procedure was a dominent project objective--the intended tool for subsequent highly efficient formulation work. Consequently, extensive systematic formulation development was not embodied in the field testing program. Thus, with a few exceptions, the field studies of vehicle formulation were exploratory rather than systematic.

A meaningful summary of three test series with respect to vehicle formulation can only be accomplished by developing suitable performance parameters. The data have shown that highway wear rates are not uniform during a single test period, and are not comparable between periods. (These facts are discussed in more detail in Section F.) Therefore, it is desirable to avoid a performance parameter based on time when comparing results of several test series. In this summary, performances are compared by reporting observations on all test paints of a series at the time the control paint (alkyd #15 or #90) of that series exhibits an integrity value of 5 and a night visibility of 10. These data are presented in Table I.

With minor reservations, Table I provides a realistic comparison of paint performance. The rather marked superiority of Urethane No. 17 and Epoxy-Polyamide No. 18 in night-visibility must be attributed in part to the beading problem with Series I. These two paints were slower drying than others, and hence they tolerated an excessive delay in the

TABLE I

RELATIVE INTEGRITY AND NIGHT VISIBILITY
OF BEAD-ON TRAFFIC PAINTS ON P/C CONCRETE

Series	Paint No.	Description	Relative Performance	
			Integrity (ASTM Grade)	Night Visibility (Hunter)
I	6	Butadiene/VT	3	2
	11	Ga. Spec. 41A	3	2
	13	Lacquer	0	2
	15	Std. Alkyd	5	10
	16	Chlor. Rub.-Alkyd, 57% PVC	8	7
	17	Moist. Cure Urethane	5	33
	18	Epoxy-Polyamide (liquid resins)	6	26
	19	Epoxy-Amine Adduct	7	8
II	29	Modified Alkyd	9	15
	36	Chlor. Rub.-Alkyd, 50% PVC	8	11
	37	Epoxy-Polyamide (solid resins)	8	9
	38	Epoxy-Amine Adduct	7	6
III	84	Chlor. Rub.-Alkyd, 57% PVC	5	15
	86	Butadiene/VT	3	4
	88	Epoxy Ester	5	16

application of beads. Subsequent tests with more practical formulations did not confirm the superiority. Catalyzed epoxies (#37, 38) appeared to enhance film integrity somewhat but contributed nothing to night visibility. Chlorinated rubber modification of a long oil alkyd (#16, 36, 84) yielded excellent performance, but similar results were achieved in a plain alkyd (#29). On the whole, of all the various vehicle materials that were evaluated, none exhibited significant superiority to the alkyd.

F. Series Correlations

In the previous discussion of formulation variables an effort was made to remove the series-to-series variation insofar as possible by relating all test results to the performance of the control paint. Now, by observing the series-to-series variation in the control paint, an idea of the magnitude of the effect may be gained. In Figure 6, A and B, paint integrity and night visibility versus exposure time are plotted for the alkyd control paint in each test series.

Both plots show that the rate of wear is different for each series. Series I was much slower than Series II or III. This is entirely consistent with the erosive failure mode of Series I as compared with extensive chipping observed in Series II and III. One notes also that in Series I the rate of failure (slope) diminishes with time and tends to flatten out. Initially rapid erosive wear on surface "peaks" is followed by a long period of negligible erosion in "valleys." In contrast with this, the chipping failures of Series II and III progress at a fairly constant high rate throughout the life of the film. "Valleys" provide little or no protection against chipping failure. The night visibility curves are generally similar except that the rate of loss

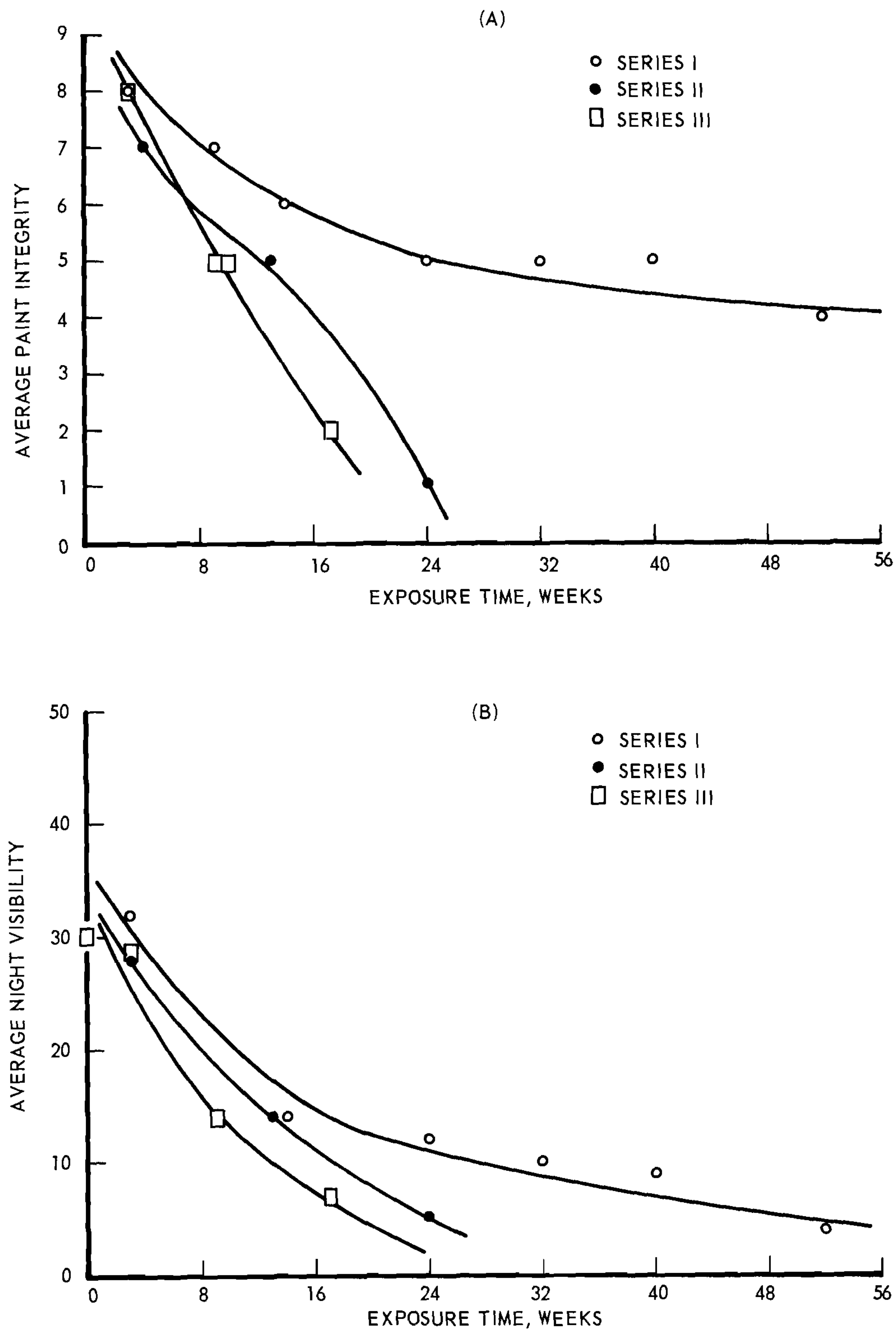


Figure 6. Integrity and Night Visibility of Control Paint, Beaded on P/C Concrete for Three Test Series.

(slope) decreases with time in all cases. Initial bead losses appear to occur at a uniformly high rate for all series. How may one explain the marked differences observed in the performance of this single paint? The most likely sources of variation would be:

1. Formulation errors
2. Grading or instrumental errors
3. Application method
4. Seasonal effects
5. Traffic load
6. Surface conditions

It has been shown within the scope of this program that some moderate formulation variations can cause substantial performance changes. However, particular care and attention was directed to the preparation and checking of formulations so as to minimize such errors. Accordingly, this factor is considered to be a negligibly small source of error.

Grading errors, on the other hand, cannot be dismissed as negligible. Even with the assistance of photographic standards, the assignment of integrity values should not be considered to have a precision of better than ±1 unit. Field night visibility determinations with the Hunter instrument also exhibit poor precision. These difficulties are compensated for to a considerable extent by the fact that each point in Figure 6 represents the average of three integrity observations or nine night visibility measurements, respectively. Granting that random errors contribute some uncertainty to the data, the more serious possibility is that a systematic bias might have occurred among the series. In view of the use of grading and instrumental standards, it is not probable that such a bias could be as large as the indicated differences between

Series II and III, and it certainly could not approach the differences between Series I and II.

Application methods were uniform throughout the three series with the exception of the delayed beading in Series I. If this delayed beading were to produce any effect, it would be to impair performance of Series I, which would tend to reduce rather than increase differences in performance among the three series. This source of error may, then, be neglected.

Seasonal effects on wear rates cannot be completely discounted. A qualitative summary follows:

Series	I	II	III
Seasonal Severity	moderate	intermediate	severe
Performance (weeks to 5-integrity)	25	12	9

It is certain that a greater difference in seasonal severity occurred between Series II and III than between Series I and II, but the results do not reflect corresponding performance differences. Accordingly, the seasonal effect is probably a secondary factor in the present studies.

Traffic loads have been checked for the test periods in question with the following results:

Series	I	II	III
Average Daily Count	31,361	25,498	32,343

No systematic relation to observed paint performance was indicated.

Surface conditions have been singled out, partially by the foregoing process of elimination and partially by inference from other work, as the probable major source of performance variations in the control paint among the test series. The term "surface conditions" must remain somewhat vague; they are not characterized either in terms of basic physical properties or by arbitrary test methods. Clearly, as demonstrated in laboratory work (cf. Part III of this report), variations in surface conditions can cause gross differences in paint performance. The mode of paint failure may change from erosion to chipping when surface conditions affect adhesion. Since no characterization of the highway test surfaces had been considered at the outset of this program, no data are available to permit objective correlation with performance observations. The only direct evidence available is the opinion of the investigators that the highway surface of Series III was definitely more contaminated with droppings of vehicles than either Series I or II. This contamination, together with other possible variations in surface conditions of the highway, appears to be the probable cause of the earlier loss of adhesion in Series II and III with consequent chipping.

V. GENERAL OBSERVATIONS AND CONCLUSIONS

Specific conclusions pertaining to individual studies have been presented in appropriate sequence, and the findings of the three test series were summarized in the previous section. The following conclusions are applicable to the whole of the highway test studies.

A. Formulation Variables

If highway test data are to be correlated with laboratory tests and with paint physical properties, it is mandatory that the highway tests reliably reflect all variations in paint formulation that affect performance. Any single highway study involves numerous variables, other than formulation, that are difficult or impossible to control. While the present program did not lend itself to rigorous statistical analysis, it was possible to assess some of the other sources of variation. When test designs include use of control paints, and application of several film thicknesses of each paint, much of the statistical "noise" can be removed from the experiment. Further reduction in the noise would be desirable; however, the present studies yielded distinct discrimination between good and poor paint formulations. Among the better paints, increasing difficulty was experienced in attempting to determine the order of performance. One might be tempted to conclude in these cases that the differences were negligibly small, and that these paints may be crowding against some type of performance "ceiling." The data are certainly insufficient to justify such a conclusion, and it is more appropriate to recommend that further consideration be given to improved designs and methods of highway studies, and to more comprehensive characterization of paint physical properties. This topic will be discussed further in Part III of this report.

B. Substrate Variables

Differences in paint performance on P/C concrete versus asphalt were shown clearly in Series I. However, larger differences among the several series on concrete have been attributed primarily to the variability of the substrate. The use of a control paint does not preclude the possibility that individual paints may interact differently with substrate variations. Methods are needed for characterizing paint bonding qualities of the substrate and, ultimately, for improving the bonding characteristics of inadequate substrates.

C. Application Variables

Difficulties with beading equipment were discussed in connection with Series I. Corrections were made and utilized in Series II and III. By the time the testing program was concluded, it had become fully apparent that the utmost precision in beading is required. The performance factor of night visibility depends directly upon precise bead application, making that factor as important as control of paint film thickness if representative results are to be obtained. Accordingly, still further improvements in beading equipment would undoubtedly reduce this source of test variance significantly.

Aside from occasional operating problems, the paint application equipment was found to function adequately for experimental purposes. This is a minor source of variance, and there is little to be gained by efforts to reduce it further.

D. Time and Seasonal Variables

The only complete solution to the control of the time variable is to avoid any effort at correlations between annual series, but this is neither practical nor desirable. By placing annual tests at the same time each year, some reduction in variability may be realized. In any event, the use of control paints is essential. It is the opinion of the investigators that substrate variation in these series was a substantially greater factor than season of application except to the extent that substrate bonding characteristics (e.g., moisture retention) might vary seasonally. Again, the absence of substrate characterizations limits reliable conclusions.

E. Observed Performance Variables

The accuracy and precision of performance observations obviously control the validity of all conclusions. Much technical effort was expended at the beginning of this project in an endeavor to measure paint film thickness and wear on the highway by use of a beta backscatter thickness gage (see Introduction, Part I); however, this technique was not feasible in practice. Paint integrity has instead been measured as visual gradings, using the ASTM photographic standards. Despite the semi-quantitative nature of these gradings, it is evident that an adequate measure of relative performance is obtained. Measurement of night visibility is somewhat less satisfactory because of difficulties in maintaining calibration and in meeting the precise geometrical requirements for each field measurement with the Hunter Meter. In the present study these difficulties were resolved by replicating observations and by utilizing a "back up" instrument to detect gross errors. There is definite need for an improved instrument for measuring night visibility.

APPENDIXES

A. Paint Formulations

Project No. B-210

Date 6/20/62

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 15

TT - P - 115, white

	% WEIGHT	% VOLUME	100 GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	48.0	21.2				
Rutile 610 - TiO_2	29.8	20.8	150	35.0	4.3	680
Gamaco	29.8	32.4	150	22.6	6.7	680
Celite 281	19.8	25.1	100	19.2	5.2	454
Nytal 300	19.8	20.3	100	23.8	4.2	454
Bentone 38	0.8	1.4	4	15.0	0.3	18
	100.0	100.0	---		---	---
			504		20.7	2286
VEHICLE	52.0	78.8				
Alkyd P 670-55	69.1	65.8	377	7.5	50.3	1710
VM & P Naphtha	28.2	32.0	154	6.3	24.5	700
Cobalt Naphth. - 6%	0.5	0.5	3.0	8.0	0.4	13.6
Lead Naphth. - 24%	1.4	1.0	7.5	9.6	0.8	34
Mn Naphth. - 6%	0.2	0.3	1.0	8.1	0.2	4.5
Adv. Anti-skin agent	0.6	0.5	3.5	7.8	0.4	15.9
			546.0		76.6	2478.0
	100.0	100.1	1050		97.3	4764.0

WEIGHT PER GALLON 10.8 LBS.

200g VM % P used for grinding

P.V.C. 48.0 %

TOTAL SOLIDS:

WEIGHT 68.1 %

VOLUME 44.3 %

Project No. B-210

Date 3/7/63

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 29

Ga. Tentative Specification #4

White Traffic Line Paint

	% WEIGHT	% VOLUME	100 GALLON BATCH			
PIGMENT	50.0	20.3	Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
Rutile 610 TiO_2	28.4	6.7	142	35.0	1.2	645
Gamaco	30.0	37.1	150	22.6	6.6	681
Celite 281	20.8	30.3	104	19.2	5.4	472
Nytal 300	20.8	23.6	100	23.8	4.2	454
Al. Stearate	0.8	2.2	4	10.0	0.4	18
	100.0	100.0	500		17.8	
VEHICLE	50.0	79.7				
Alkyd P 670-55	73.0	70.1	365	7.5	48.7	1657
V M & P Naphtha	24.3	27.8	121.5	6.3	19.3	552
Cobalt Naphth. - 6%	0.5	0.4	2.5	8.0	0.3	11.4
Lead Naphth. - 24%	1.4	1.0	7.0	9.6	0.7	32
Mn Naphth. - 6%	0.2	0.1	1.0	8.1	0.1	4.5
Adv. anti-skin agent	0.6	0.6	3.0	7.8	0.4	13.6
			500.0		69.5	
	100.0	100.0	1000.0		87.5	

WEIGHT PER GALLON 11.4 LBS.

P.V.C. 45.4 %

TOTAL SOLIDS:

WEIGHT 70.3 %

VOLUME 44.8 %

Project No. B-210

Date 7/25/63

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 36

Parlin Alkyd Traffic Paint, White

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams
PIGMENT	53.2	27.3				
Rutile - 610 TiO_2	24.4	16.9	180	35.0	5.14	817
Gamaco	54.8	58.9	405	22.6	17.92	1839
Nytal 300	10.1	10.5	75	23.6	3.18	340
Celite 281	10.1	12.9	75	19.2	3.91	340
Bentone 38	0.5	0.9	4	15.0	0.27	18
	99.9	100.1	739		30.42	3354
VEHICLE	46.8	72.7				
Parlon S-10, 30% in toluene						
Parlon S-10	8.9	5.3	58	13.6	4.26	263
Toluene	20.8	23.0	135	7.25	18.62	613
Alkyd P-296-70	55.2	55.2	358	8.0	44.75	1625
Toluene	13.6	15.0	88	7.25	12.14	400
Propylene Oxide	0.6	0.7	4	7.5	0.53	18
Cobalt Naphth. - 6%	0.3	0.3	2	8.0	0.25	9
Adv. anti-skin agent	0.6	0.6	4	7.8	0.51	18
			649		81.06	2946
	100.0	100.1	1388		111.48	6300

WEIGHT PER GALLON 12.45 LBS.

P.V.C. 49.8 %

TOTAL SOLIDS:

WEIGHT 76.2 %

VOLUME 54.8 %

Project No. B-210

Date 8/30/63

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 37

Epoxy Polyamide Traffic Paint, White

	% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons	lab batch grams	
PIGMENT	57.3	30.1					
Rutile 610 - TiO_2	30.5	21.4	200	35.0	5.71	908	
Gamaco	30.5	33.2	200	22.6	8.86	908	
Nytal 300	19.1	19.7	125	23.8	5.25	568	
Celite 281	19.1	24.4	125	19.2	6.51	568	
Bentone 38	0.8	1.2	5	15.0	.33	23	
	100.0	99.9	655		26.66	2975	
VEHICLE	42.7	69.9					
Versamid 125	20.5	19.4	100	8.3	12.05	454	
Toluene	10.2	11.1	50	7.25	6.90	227	
Acetone	20.5	24.4	100	6.6	15.15	454	
Methyl Isobutyl Ketone	10.2	12.0	50	6.7	7.46	227	
EPON 1001-A-80	38.5	33.0	188	9.2	20.43	854	
			488		61.99	2216	
	99.9	99.9	1143		88.65	5191	

Total solvents used for grinding.

20 grams curing agent for 100 grams ingredients.

WEIGHT PER GALLON 12.89 LBS.

P.V.C. 49.5 %

TOTAL SOLIDS:

WEIGHT 79.2 %

VOLUME 60.8 %

Project No. B-210

Date 8/16/63

INDUSTRIAL PRODUCTS BRANCH

Paint Formulation Data

Paint No. 38

Epoxy Amine Adduct Traffic Paint, White

		% WEIGHT	% VOLUME	GALLON BATCH Pounds	Lbs. Per Solid Gal.	Gallons		
	PIGMENT	49.3	23.5					
	Rutile - 610 TiO_2	29.4	20.5	175	35.0	5.00	795	
	Gamaco	29.4	31.8	175	22.6	7.74	795	
	Celite 281	20.2	25.7	120	19.2	6.25	545	
	Nytal 300	20.2	20.7	120	23.8	5.04	545	
	Bentone 38	0.8	1.4	5	15.0	.33	23	
		100.0	100.1	595		24.36	2703	
	VEHICLE	50.7	76.5					
	EPON 1001-A-80	20.5	16.9	125	9.3	13.44	568	
	EPON 1007-CT-55	29.8	27.3	182	8.4	21.67	826	
25%	Toluene	11.5	12.2	70	7.25	9.66	318	
50%	Acetone	22.9	26.7	140	6.6	21.21	636	
25%	Methyl Isobutyl Ketone	11.5	13.1	70	6.7	10.45	318	
	Curing Agent U	2.0	1.8	12	8.5	1.41	55	
	Toluene	2.0	2.1	12	7.25	1.66	55	
				611		79.50	2776	
		100.2	100.1	1206		103.86	5479	

WEIGHT PER GALLON 11.61 LBS.

P.V.C. 52.9 %

TOTAL SOLIDS:

WEIGHT 66.9 %

VOLUME 44.4 %

775 grams composite solvent used for grinding.

1 gram curing agent for 100 grams ingredients.

Project No. B-210

Date (copied from 6/22/62 Form

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 84

Parlon-Alkyd Traffic Paint, White

	% weight	% volume	Gallon Batch Pounds	lbs/gal solid	Gallons		
PIGMENT	60.2	32.6					
TiO_2-R 610	24.8	17.2	200		5.66		
Gamaco	54.8	59.3	442		19.58		
Nytal 300	9.9	10.2	80		3.36		
Celite 281	9.9	12.5	80		4.12		
Benton 38	0.6	0.8	4		0.3		
	100	100					
VEHICLE	39.8	67.4					
Parlon S-10 Solution							
(Parlon	8.4	4.9	44.5		3.30		
Toluene)	19.5	21.3	104		14.30		
Alkyd P-296-70	51.7	51.4	275		34.37		
(Non. Vol. Portion	(36.1	(32.4	(192		(21.70		
Volatile Portion)	15.6)	19.0)	83.5)		12.67)		
Toluene	19.2	20.9	102		14.00		
Propylene Oxide	0.6	0.6	3		0.4		
6% Co. N.	0.3	0.3	1.5		0.2		
Adv. Ant. Skin.	0.6	0.6	3		0.4		
	100	100	1338		99.99G		

Consistency 88 K. U.

Weight Per Gallon 13.38

P.V.C. 56.9%

TOTAL SOLIDS

Weight 77.9%

Volume 58.0%

Project No. B-210

Date

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 85

Parlon-Alkyd "Beads In"

PIGMENT	% weight	% volume	Gallon Batch Pounds	lbs/gal solid	Gallons		
Parlon-Alkyd Pt. #84	58.0	61.7	1338	13.38	100		
(Non-Vol. Portion)	(45.1)	(35.8)	(1042)		(58.0)		
(Volatile Portion)	(12.8)	(25.9)	(296)		(42.0)		
Glass Beads	37.7	29.8	870	18.0	48.33		
Toluol	4.3	8.5	100	7.25	13.80		
	100	100					
VEHICLE							
			2308#		1621G		

Consistency 87 K.U.

Weight Per Gallon 14.24 (calc.)

B.V.C. ~~XXXXX~~. 45%

TOTAL SOLIDS

Weight 82.84%

Volume 65.60%

Project No. B-210

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 86

Date October 15, 1964

Pliolite VT

	% weight	% volume	Gallon Batch Pounds	lbs/gal solid	Gallons		
PIGMENT	54.18	26.72					
Tit. RCHT	52.96	47.38	342.6	27.07	12.66		
R-610	9.85	6.81	63.7	35.0	1.82		
Nytal 300	9.48	9.64	61.3	23.80	2.58		
Celite 281	14.85	18.72	96.1	19.20	5.00		
ASP-400	9.48	10.60	63.7	21.66	2.83		
Mica 325	1.06	1.09	6.84	23.44	0.29		
Bentone 38	0.90	1.45	5.79	15.0	0.37		
Kelcin F	1.42	4.31	9.21	8.0	1.15		
	100	100	649.24		26.70		
VEHICLE							
	45.82	73.28					
Pliolite VT	22.66	14.48	124.0	11.68	10.61		
Velsicol X-37	7.41	6.14	40.5	9.00	4.50		
Paroil 150-A	7.41	5.27	40.5	10.50	3.86		
Lactol	62.52	74.11	342.1	6.3	54.30		
	100.00	100.00	1196.3		99.97		

Consistency 80 K.U.

Weight Per Gallon 11.97 #/gal.

P.V.C. 58.47%

TOTAL SOLIDS

Weight 71.35%

Volume 45.70%

Project No. B-210

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 87

Date

Pliolite VT Paint "Beads In"

PIGMENT	% weight	% volume	Gallon Batch Pounds	lbs/gal solid	Gallons		
Pliolite Paint No. 86	61.6	67.6	1196	11.96	100		
(Non-Vol. Portion)	(44.0)	(30.9)	(854)		(45.67)		
(Volatile Portion)	(17.6)	(36.7)	(342)		(54.30)		
Glass Beads	34.5	25.0	669	18.0	37.0		
Lactol	3.9	7.4	75	6.3	10.9		
	100	100					
VEHICLE							
			1940#		147.9G		

Consistency 87 K.U.

Weight Per Gallon 13.1 (calc.)

B.V.C.
~~PXXXX~~. 45%

TOTAL SOLIDS

Weight 78.5%

Volume 55.9%

Project No. B-210

INDUSTRIAL PRODUCTS BRANCH

Date

Paint Formulation Data

Paint No. 88

Epoxy Ester

	% weight	% volume	Gallon Batch Pounds	lbs/gal solid	Gallons		
PIGMENT	50.90	23.13					
R-610 TiO_2	28.62	19.80	160.2	35.0	4.59		
Gamoco	30.24	32.39	169.3	22.6	7.49		
Celite 281	20.16	35.37	112.8	19.2	5.88		
Nytal 300	20.16	20.49	112.8	23.8	4.74		
Al. Stearate (#27)	0.81	1.95	4.51	10.0	0.45		
	100.00	100.00	559.7		23.15		
VEHICLE							
	49.10	76.87					
Epoxy Ester Alkyd - 55% Solids, LX-1	76.28	74.42	411.9	7.20	57.20		
(Solids)			(226.6		(27.80)		
(Thinners)			(185.3)	6.3	(29.40)		
Lactol	20.90	23.31	112.8	6.3	17.91		
24% Lead Naphthenate	1.45	1.07	7.90	9.6	0.82		
6% Cobalt Naphthenate	0.52	0.46	2.82	8.0	0.35		
6% Manganese Naphthenate	0.21	0.18	1.13	8.1	0.14		
Exkin #1	0.62	0.56	3.39	7.8	0.43		
	100.00	100.00	1100.0		100.00		

Consistency 89 K.U.

Weight Per Gallon 11.00 #/gal.

P.V.C. 45.41%

TOTAL SOLIDS

Weight 71.50%

Volume 50.93%

Project No. B-210

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 89

Date

Epoxy Ester "Beads In"

	% weight	% volume
PIGMENT		
Epoxy Ester Pt. No. 88	57.7	65.6
(Non-Vol. Portion)	(41.4)	(33.5)
(Volatile Portion)	(16.3)	(32.1)
Glass Beads	38.5	26.7
Lactol	3.8	7.7
	100	100
VEHICLE		

Gallon Batch				
Pounds	lbs/gal solid	Gallons		
1100	11.00	100		
(790)		(51.0)		
(310)		(49.0)		
734	18.0	40.7		
74	6.3	11.7		
1908		152.4		

Consistency 86 K.U.

Weight Per Gallon 12.5 (calc.)

B.V.C. ~~XXXXX.~~ 45%

TOTAL SOLIDS

Weight 79.9%

Volume 60.2%

Project No. B-210

Date

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 90

Standard Alkyd

	% weight	% volume	100 Gallon Batch				
			Pounds	lbs/gal solid	Gallons	lab batch grams	
PIGMENT	48.0	21.2					
Rutile 610 - TiO_2	29.8	20.8	150	35.0	4.3	680	
Gamaco	29.8	32.4	150	22.6	6.7	680	
Celite 281	19.8	25.1	100	19.2	5.2	454	
Nytal 300	19.8	20.3	100	23.8	4.2	454	
Bentone 38	0.8	1.4	4	15.0	0.3	18	
	100.0	100.0	---		---	---	
			504		20.7	2286	
VEHICLE	52.0	78.8					
Alkyd P 670-55	69.1	65.8	377	7.5	50.3	1710	
VM&P Naphtha	28.2	32.0	154	6.3	24.5	700	
Cobalt Naphth. - 6%	0.5	0.5	3.0	8.0	0.4	13.6	
Lead Naphth. - 24%	1.4	1.0	7.5	9.6	0.8	34	
Mn Naphth. - 6%	0.2	0.3	1.0	8.1	0.2	4.5	
Adv. Anti-skin agent	0.6	0.5	3.5	7.8	0.4	15.9	
			546.0		76.6	2478.0	
	100.0	100.1	1050		97.3	4764.0	

Consistency

Weight Per Gallon 10.8 lbs.

P.V.C. 48.0%

TOTAL SOLIDS

Weight 68.1%

Volume 44.3%

Project No. B-210

Date

INDUSTRIAL PRODUCTS BRANCH
Paint Formulation Data
Paint No. 91

Std. Alkyd-"Beads In"

PIGMENT	% weight	% volume	Gallon Batch Pounds	lbs/gal solid	Gallons		
Reg. Alkyd Pt. #90	60.5	68.5	1080	10.8	100		
(Non-Vol. Portion)	(41.1)	(30.8)	(733)		(45.-)		
(Volatile Portion)	(19.4)	(37.7)	(347)		(55.-)		
Glass Beads	35.6	24.0	635		35.0		
Lactol	3.9	7.5	69		11.0		
	100	100					
VEHICLE							
			1784#		146.0G		

Consistency 84 K.U.

Weight Per Gallon 12.2 (calc.)

B.V.C.
~~XXXXXX~~ 45

TOTAL SOLIDS

Weight 76.7%

Volume 54.8%

B. Performance Data

TABLE II

WEATHERING DATA, SERIES II - APPLIED 7/3/63

Paint No.	Film Th. (mils)	Line No.	One Month Chipping	One Month Hunter Night Visibility	Three Months Chipping	Three Months Hunter Night Visibility	Six Months Chipping	Six Months Hunter Night Visibility
15	10	101	6	9	3	4.3	0	1.35
	15	102	7	25	5	13.5	1	1.50
	20	103	8	51	6	22.6	2	13.00
29	10	104	9	27	7	18.6	1	2.00
	15	105	10	43	9	21	2	5.50
	20	106	10	53	10	19.3	2	9.50
36	10	107	7	20	6	13	1	0.60
	15	108	8	56	8	18.6	1	1.80
	20	109	7	62	7	14	2	2.00
37	10	110	6	19	5	8.6	1	3.50
	15	111	8	35	8	13.6	2	1.60
	20	112	10	43	9	25	3	11.00
38	10	113	6	10	4	3.4	0	1.30
	15	114	8	15	7	9.6	3	1.30
	20	115	9	23	7	12.7	4	6.00

TABLE III

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
INITIAL OBSERVATIONS

Beaded-Unbeaded	Reg. Alkyd B	Reg. Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
				Integrity					
Paint No. 0% BVC	90	90	88	88	84	84	86	86	90
10 mils	10	10	10	10	10	10	10	10	
15 mils	10	10	10	10	10	10	10	10	10
20 mils	10	10	10	10	10	10	10	10	
Paint No. 45% BVC	91	91	89	89	85	85	87	87	
20 mils	10	10	10	10	10	10	10	10	
30 mils	10	10	10	10	10	10	10	10	
				Hunter Night Visibility[o]					
Paint No. 0% BVC	90	90	88	88	84	84	86	86	90
10 mils	45(32)	1.03(8)	18(20)	0.8(7)	14.0(40)	1.0(10)	40(7)	30(7)	
15 mils	25(24)	1.0(5)	20(20)	1.0(7)	4.0(26)	1.0(10)	30(52)	1.6(10)	50
20 mils	20(57)	0.8(5)	8(34)	5.0(10)	20.0(23)	2.0(8)	10(59)	1.4(9)	
Paint No. 45% BVC	91	91	89	89	85	85	87	87	
20 mils	20(34)	25(10)	25(33)	2.0(8)	25(17)	2.3(12)	11(64)	0.4(15)	
30 mils	6(50)	3.5(11)	30(43)	2.5(10)	40(38)	1.2(12)	0.8(70)	1.0(13)	
				Special Reflectance					
Paint No. 0% BVC	90	90	88	88	84	84	86	86	90
10 mils	34	16	26	15	43	18	15	15	
15 mils	30	14	26	15	32	18	52	18	29
20 mils	56	14	38	18	28	16	60	17	
Paint No. 45% BVC	91	91	89	89	85	85	87	87	
20 mils	32	18	35	16	24	20	62	22	
30 mils	50	19	45	18	41	20	67	21	

[o] The Hunter instrument was observed to be functioning erratically during these measurements, therefore approximate equivalents based on the Special Reflectance measurements were computed and are shown in parentheses.

TABLE IV

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
3 WEEKS OBSERVATIONS

Beaded-Unbeaded	Reg. Alkyd B	Reg. Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
Integrity[x]									
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	7	4	8	7	7	6	6[xx]	7[xx]	
15 mils	9	4	9	6	9	8	7[xx]	9[xx]	8
20 mils	8	5	9	7	10	8	9[xx]	9[xx]	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	8	7	9	8	7	8	7[xx]	8[xx]	
30 mils	9	7	7[xx]	7[xx]	10	9	8[xx]	8[xx]	
Hunter Night Visibility									
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	26	3	40	4	13	3	20	3	
15 mils	25	2	30	4	45	2.5	18	3.5	22
20 mils	36	3	19	2	40	4	10	4	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	20	6	20	8	18	5	15	14	
30 mils	30	12	12	9	35	3	18	14	
Special Reflectance									
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	10	10	13	9	9	7	13	9	
15 mils	17	4	15	9	18	9	11	8	18
20 mils	26	5	26	9	18	8	11	9	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	13	10	12	9	12	11	10	10	
30 mils	16	11	12	9	15	11	11	10	

[x] Integrity determinations were based on chipping with exceptions noted.

[xx] These paints showed integrity failure by erosion or smearing rather than chipping.

TABLE V

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
9 WEEKS OBSERVATIONS

Beaded-Unbeaded	Reg. Alkyd B	Reg. Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
Integrity[x]									
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	5	2	2	3	3	3	2[xx]	2[xx]	
15 mils	5	1	5	3	5	4	3[xx]	3[xx]	8[xx]
20 mils	6	1	8	3	6	3	4[xx]	4[xx]	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	6	6	6	5	6	4	6[xx]	7[xx]	
30 mils	6	5	5	5	5	5	7[xx]	7[xx]	
Hunter Night Visibility[o]									
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	7	1	10	2	1[o](0)	20[o](0)	2	1	
15 mils	11	1	15	17	2.5[o](5)	27[o](4)	2	1	11
20 mils	24	1	2	4	2[o](4)	2[o](4)	2	3	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	9	6	10	5	12	6	9	9	
30 mils	12	8	12	10	16	5	9	9	
Special Reflectance									
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	10	8	9	7	6	7	9	7	
15 mils	11	6	11	6	14	12	9	9	15
20 mils	18	6	12	8	18	12	11	11	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	11	12	13	12	10	11	9	10	
30 mils	13	9	12	11	14	14	9	10	

[x] Integrity determinations were based on chipping with exceptions noted.

[xx] These paints showed integrity failure by erosion or smearing rather than chipping.

[o] The Hunter Instrument obviously gave some false readings.
Figures in parenthesis are based on equivalents from the special reflectometer and converted to Hunter readings based on previously prepared correlation charts.

TABLE VI

HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
10 WEEKS OBSERVATIONS

Beaded-Unbeaded	Reg. Alkyd B	Reg. Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
				Integrity[x]					
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	4	3	3	4	3	3	2^{xx}	2^{xx}	
15 mils	4	2	4	3	3	3	$4^{\boxtimes}$	$4^{\boxtimes}$	7
20 mils	6	2	6	2	3	2	$4^{\boxtimes}$	$4^{\boxtimes}$	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	4	4	4	4	4	3	$3^{\boxtimes}$	$3^{\boxtimes}$	
30 mils	4	3	4	4	3	3	$4^{\boxtimes}$	$4^{\boxtimes}$	

No observations for night visibility were made at this time.

---

x Integrity determinations were based on chipping with exceptions noted.

xx These paints showed integrity failure by erosion or smearing rather than chipping.

$\boxtimes$ Paint stripes show chipping and erosion.

TABLE VII

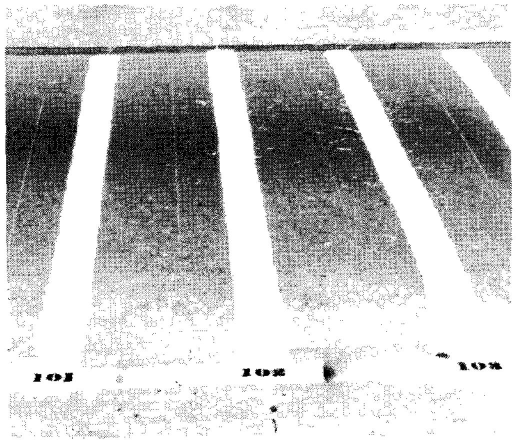
HIGHWAY TEST STRIPES, SERIES III - APPLIED 11/12/64
17 WEEKS OBSERVATIONS

Beaded-Unbeaded	Reg. Alkyd B	Reg. Alkyd U	Epoxy Ester B	Epoxy Ester U	Parlon-Alkyd B	Parlon-Alkyd U	Pliolite B	Pliolite U	Two Coats (15 mils)
				Integrity[x]					
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	2	2	1	2	1	2	1^{xx}	1^{xx}	5
15 mils	2	1	3	3	2	2	2^{xx}	2^{xx}	
20 mils	2	1	4	2	1	1	2^{xx}	3^{xx}	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	2	2	3	2	2	1	1^{xx}	1^{xx}	
30 mils	2	2	3	2	1	1	2^{xx}	2^{xx}	
				Hunter Night Visibility					
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	3	0.4	9	2	1	1	4	1	
15 mils	7	1	7	2	12	2	2	5	12
20 mils	11	1	18	2	18		3	2	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	9	7	9	6	12	9	16	10	
30 mils	12	6	13	10	14	12	11	13	
				Special Reflectance					
Paint No.	90	90	88	88	84	84	86	86	90
0% BVC									
10 mils	6	7	8	8	5	7	9	9	
15 mils	5	8	7	8	8	9	9	12	11
20 mils	8	5	15	10	9	8	11	12	
Paint No.	91	91	89	89	85	85	87	87	
45% BVC									
20 mils	8	8	7	9	7	8	10	8	
30 mils	10	9	9	9	8	6	8	9	

x Integrity determinations were based on chipping with exceptions noted.

xx These paints showed integrity failure by erosion or smearing rather than chipping.

C. Test Stripe Photographs



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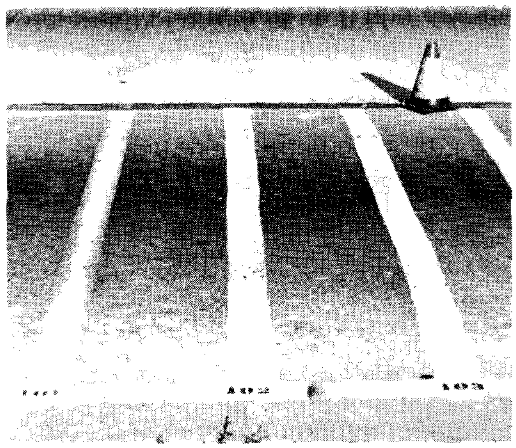
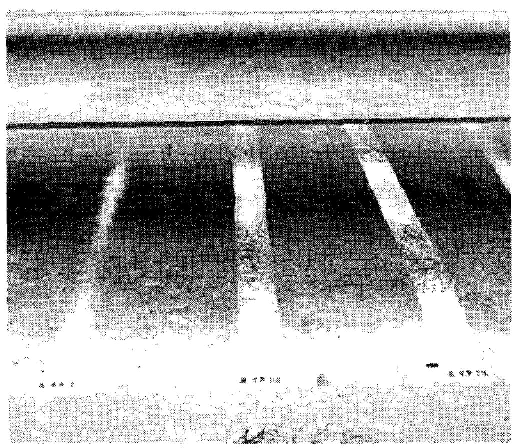
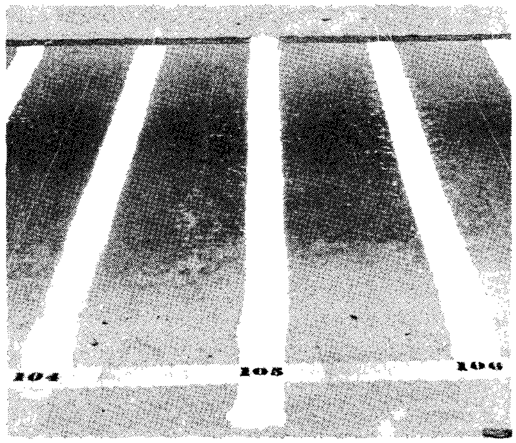


3 MONTHS



6 MONTHS

Figure 7. Weathering of Regular Alkyd (#15), Series II.



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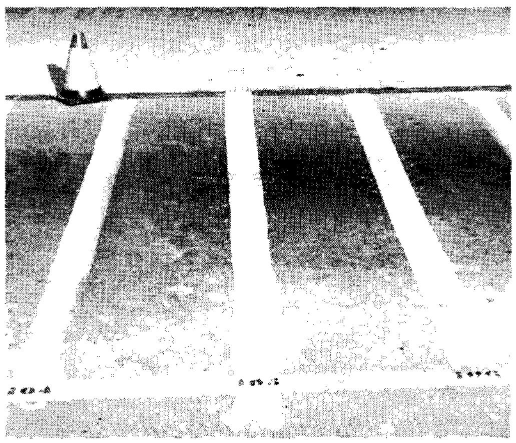
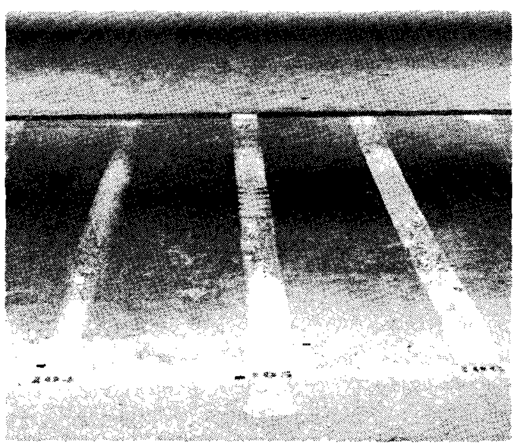
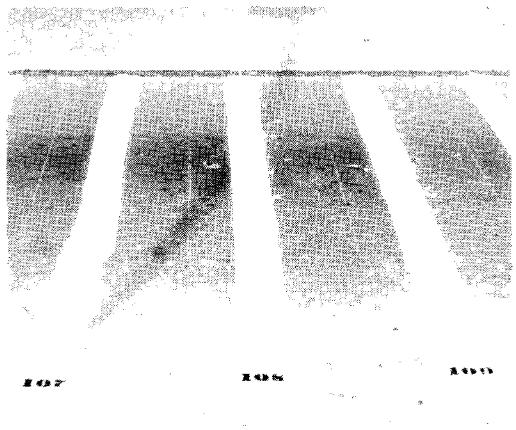


3 MONTHS



6 MONTHS

Figure 8. Weathering of "Minimum" Alkyd (#29), Series II.



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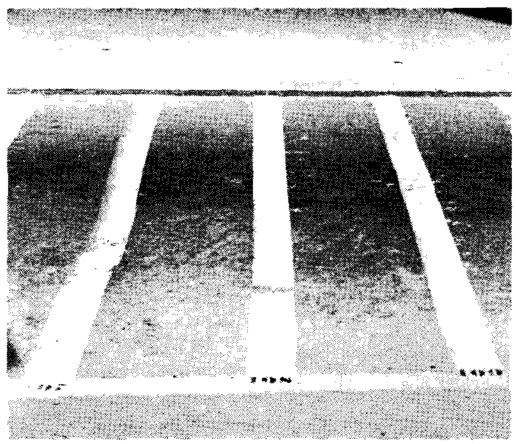

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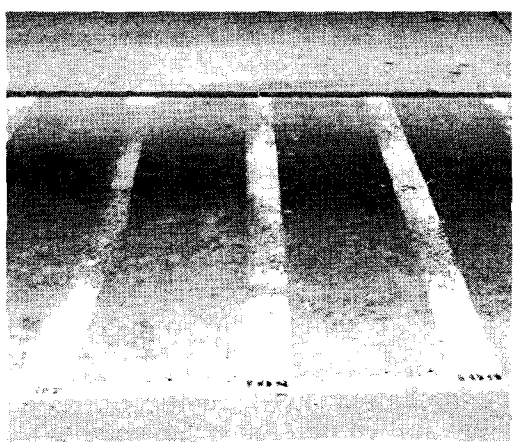
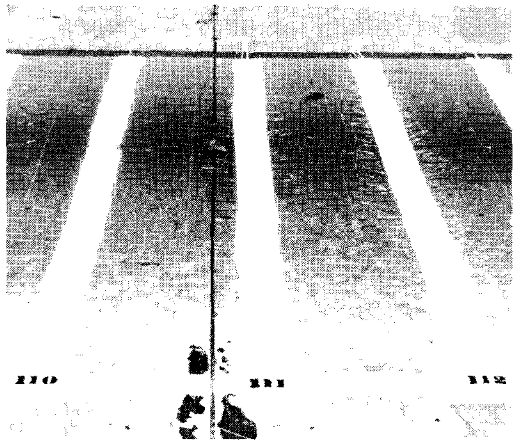


6 MONTHS

Figure 9. Weathering of Chlorinated Rubber-Alkyd (#36), Series II.

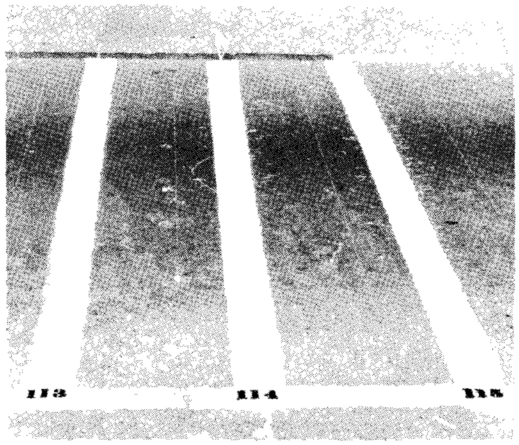


INITIAL

3 MONTHS

6 MONTHS

Figure 10. Weathering of Epoxy-Polyamide (#37), Series II.



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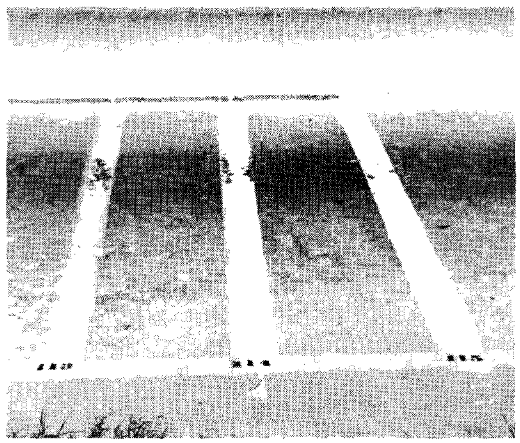
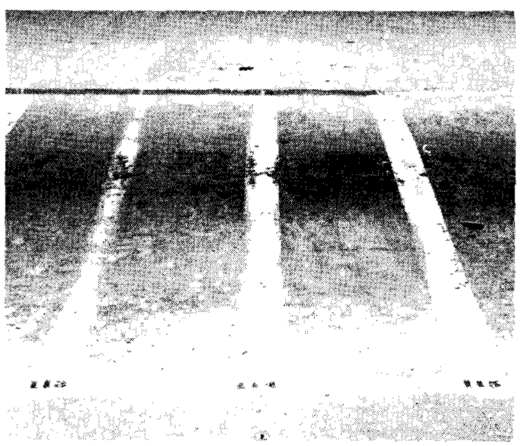


3 MONTHS



6 MONTHS

Figure 11. Weathering of Epoxy-Amine Adduct (#38), Series II.

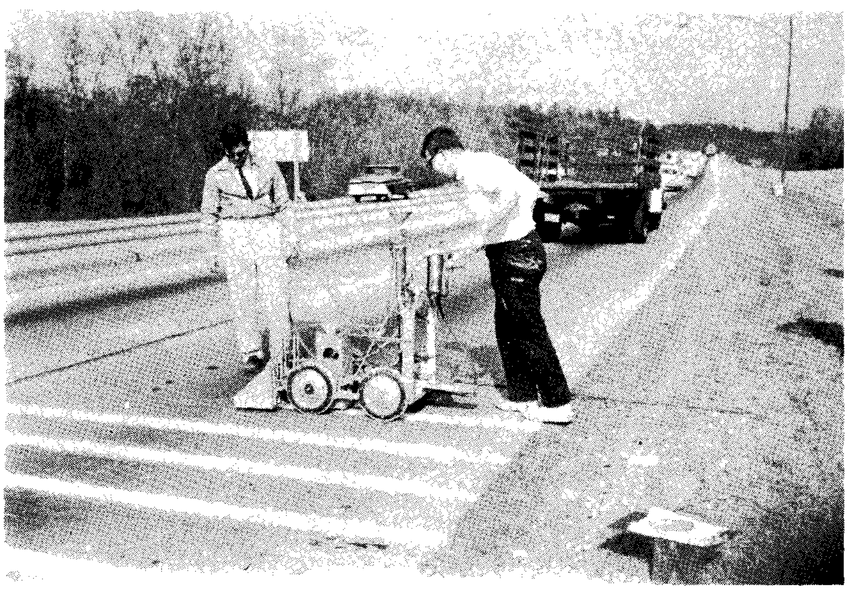
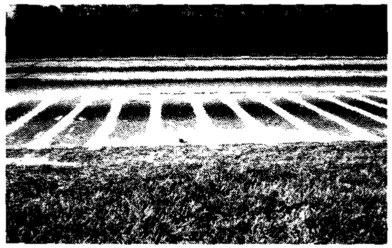


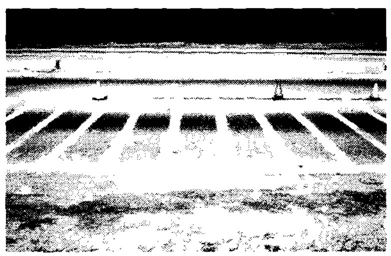
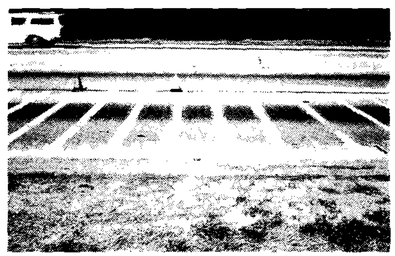
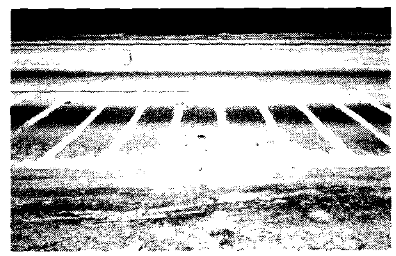
Figure 12. Highway Site and Application Work, Series III.

STD. ALKYD (NO. 90) | EPOXY ESTER (NO. 88) | CHL. RUB.-ALKYD (NO. 84) | B/VT RESIN (NO. 86)

LINES 201-207 | 208-213 | 214-219 | 220-225

INITIAL

LINES 201-204 | 208-213 | 214-219 | 220-225

17 WEEKS WEATHERING

Figure 13. Weathering of 0% BVC Paints, Series III.

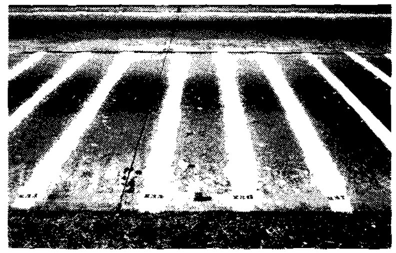
STD. ALKYD (NO. 91)

LINES 226-229

EPOXY ESTER (NO. 89)

230-233

CHL. RUB-ALKYD (NO. 85)

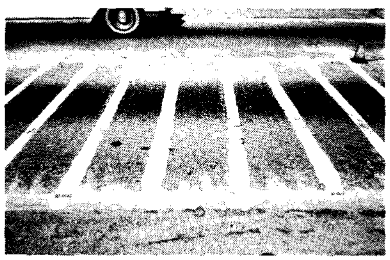


234-237

B/VT RESIN (NO. 87)

238-241

INITIAL



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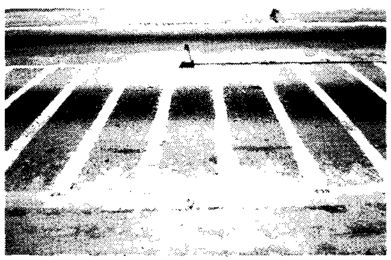

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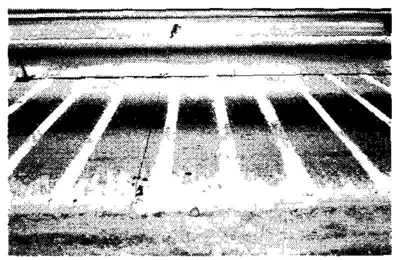
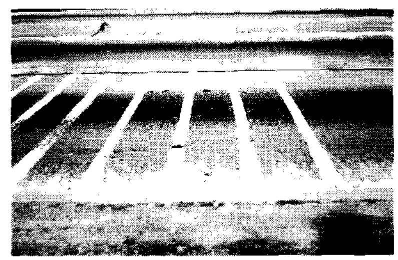


234-237



238-241

17 WEEKS WEATHERING

Figure 14. Weathering of 45% BVC Paints, Series III.

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia

FINAL TECHNICAL REPORT

Georgia Tech Project B-210

Research Project HPS-1(60)

USE OF RADIOISOTOPES IN DEVELOPMENT OF TEST METHODS AND FORMULATIONS FOR TRAFFIC PAINTS

By

W. R. TOOKE, JR. and W. H. BURROWS

PART III

LABORATORY WEAR TEST STUDIES

SEPTEMBER 30, 1965

Prepared for
STATE HIGHWAY DEPARTMENT OF GEORGIA

in cooperation with
U. S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

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I. INTRODUCTION

A. Developmental Activities

The experimental point-of-departure of this project was Hickson's 1/ classic paper, and the testing machine disclosed therein. This machine in its original form evaluates traffic paints probably as well as most machines now in use. Subsequent contributions to the art of accelerated laboratory wear testing of traffic paints have been relatively trivial.

Developmental activities were directed first at correcting certain mechanical shortcomings that were observed in use of the machine. Later, additional features were added to simulate environmental parameters, and operating conditions were modified to properly balance these parameters. From the outset, the problem was not simply to distinguish good and bad paints, but rather to discriminate reliably among the better paints. Corollary problems of test panel preparation, film thickness measurement, beading, integrity, and night visibility evaluation were resolved in the course of the developmental work.

When Series II highway tests (Part II, this report) indicated that any paint may fail by either an erosive or a chipping mechanism, we were forced to realize that a single accelerated test should not be expected to predict relative resistance to both failure mechanisms simultaneously. Thereafter, rapid progress was made in developing dual testing procedures to evaluate these failure mechanisms separately.

It would be misleading to state that all operational problems were solved to our complete satisfaction during this developmental phase of activity. Nevertheless, much progress was made in controlling variables to achieve acceptable reliability. The machine and procedures were developed to a point that was believed to approach its maximum inherent capabilities.

Fundamental limitations in attaining dynamic similitude with highway conditions were recognized, accepted, and at least partially compensated for, with the result that comprehensive performance evaluations could then be made with confidence.

B. Highway Test Correlations and Substrate Effects

Recognizing that adequate correlation could be obtained only by performing accelerated wear testing under two separate sets of operating conditions--to evaluate susceptibility to erosion and chipping independently--performance evaluations on the accelerated wear tester subsequently yielded data which correlated well with highway test data. The erosion test appeared to be very satisfactory for providing evaluations of erosion resistance with good precision. The test for chipping presented some difficulties which demanded more replication of tests to achieve adequate precision. These difficulties were also experienced on the highway. The chipping phenomenon is intimately related to paint-substrate adhesion, and numerous characteristics of the substrate affect this adhesion. Chipping failure of paint tends to be erratic because of characteristics which we are at present unable to adequately define or control.

Efforts to obtain a better understanding of some of the elements of practical adhesion utilizing the accelerated wear tester were most rewarding. Waxy contamination of any substrate was observed to dominate all other factors in reducing adhesion. Surface permeability and roughness promoted adhesion. Concrete test surfaces respond in a manner which is consistent with additivity of the varied surface characteristics of a heterogeneous material.

C. Property Characterization - Performance Relations of Paints

This study was limited to a brief investigation of physical test characteristics and physical changes of traffic paints when the films are subjected to oven ageing. The premise of the study was that properties and property changes are related to paint performance, and some of the relationships may be quite direct and simple. It was feasible to perform only a few paint film tests, and these tests do not measure single properties unambigiously; nevertheless, it was clearly demonstrated that ageing imparts significant changes, and that several indicated film characteristics of paints are consistent with laboratory and field performance tests of the same paints. Film tests which characterize adhesion would appear to be of greatest value as a guide to paint formulation.

This brief investigation indicated that a more intensive study of film characterization should be highly rewarding at all levels of traffic paint research and development.

D. Theoretical Studies

The force and energy equilibrium equations for fluid pressures applied to a film were solved in terms of film physical properties. The resulting relations were utilized in rate equations to provide a mathematical model of traffic paint performance. Existing data was insufficient to permit explicit solutions of the rate equations; but interpretations of experimental findings were enhanced, and the proper directions for future research were more precisely defined.

II. INITIAL EXPERIMENTAL STUDIES

A. Wear Tester Design

Numerous designs of traffic paint testing machines have been described in the literature 1/, 2/, 3/, 4/. These machines vary greatly in complexity, size, and capability for simulating practical service conditions, but none is capable of fully simulating tire-surface dynamics. Much consideration was given to various features of design, including some original designs. Considering all the requirements that a research device would have to meet, we concluded that the Hickson Traffic Paint Abrasion Machine as described in Federal Specification TT-P-115A would provide the best point-of-departure for developing useful laboratory testing procedures.

A photograph of the machine as initially constructed for this project is shown in Figure 1. The driving wheel, fitted with the specified special rubber ring (Eberhard-Faber Special Eraser Stock No. 1071), is actuated by timing belts connected to a gear-reduction motor. The speed of the driving wheel is approximately 40 RPM, and the load on the test surface is 40 pounds, as required by the specification. As shown in Figure 1, the horizontal turntable supports testing discs on which test paints are applied. Additional original features not shown in the photograph were an RPM counter for the turntable and a water-dropping container mounted over the disc to provide wet-surface tests.

B. Exploratory Experiments

Early tests were intended to explore various methods of stripe application to various surfaces before deciding in favor of any particular test procedure. The first tests were conducted on trowled surfaces of

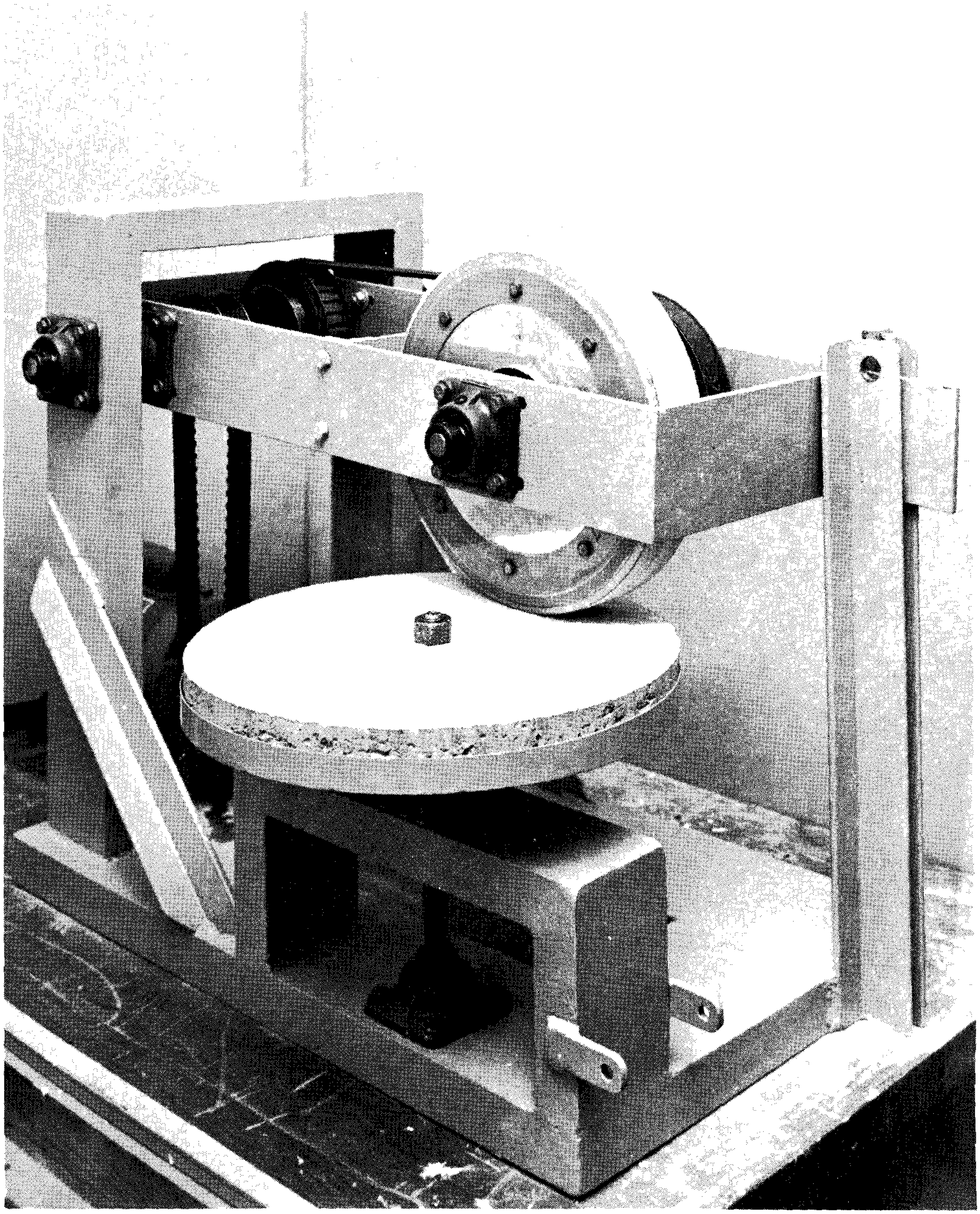

Figure 1. Orginal Wear Test Machine.

concrete discs, prepared as described in Appendix A, and on the smooth surfaces of transite, an alternative to the rough textured concrete. Paint was applied by spray in these experiments and paint film thickness was not precisely controlled. Panels were tested both wet and dry.

Some typical results are shown in Figure 2. Paint stripes at 6:00, 3:00, 12:00, and 9:00 o'clock on each panel consist of 2, 4, 6, and 8 spray passes of paint, respectively. The film thickness effect is clearly evident. The superior uniformity of wear on the transite panels is also evident.

C. Testing Procedures

The exploratory experiments led to an initial "standardization" of testing conditions, summarized as follows:

INITIAL STANDARD TEST CONDITIONS

Substrate: Transite, smooth side

Paint Application Method: Doctor blade

Film Thickness: 15 mils wet

Drying Time: 7 days

Operating Conditions: Replicate panels tested dry and soaking wet

Evaluation: Based on cycles to failure as defined by ASTM D-821-47 Erosion, condition 5.

D. Test Results and Observations

Some test results based on the above described conditions are given in Table I. These results clearly indicated:

(1) Substantial differences in wear resistance among conventional paints,

(2) Marked superiority of wear resistance of special paint types (epoxies, urethane), and

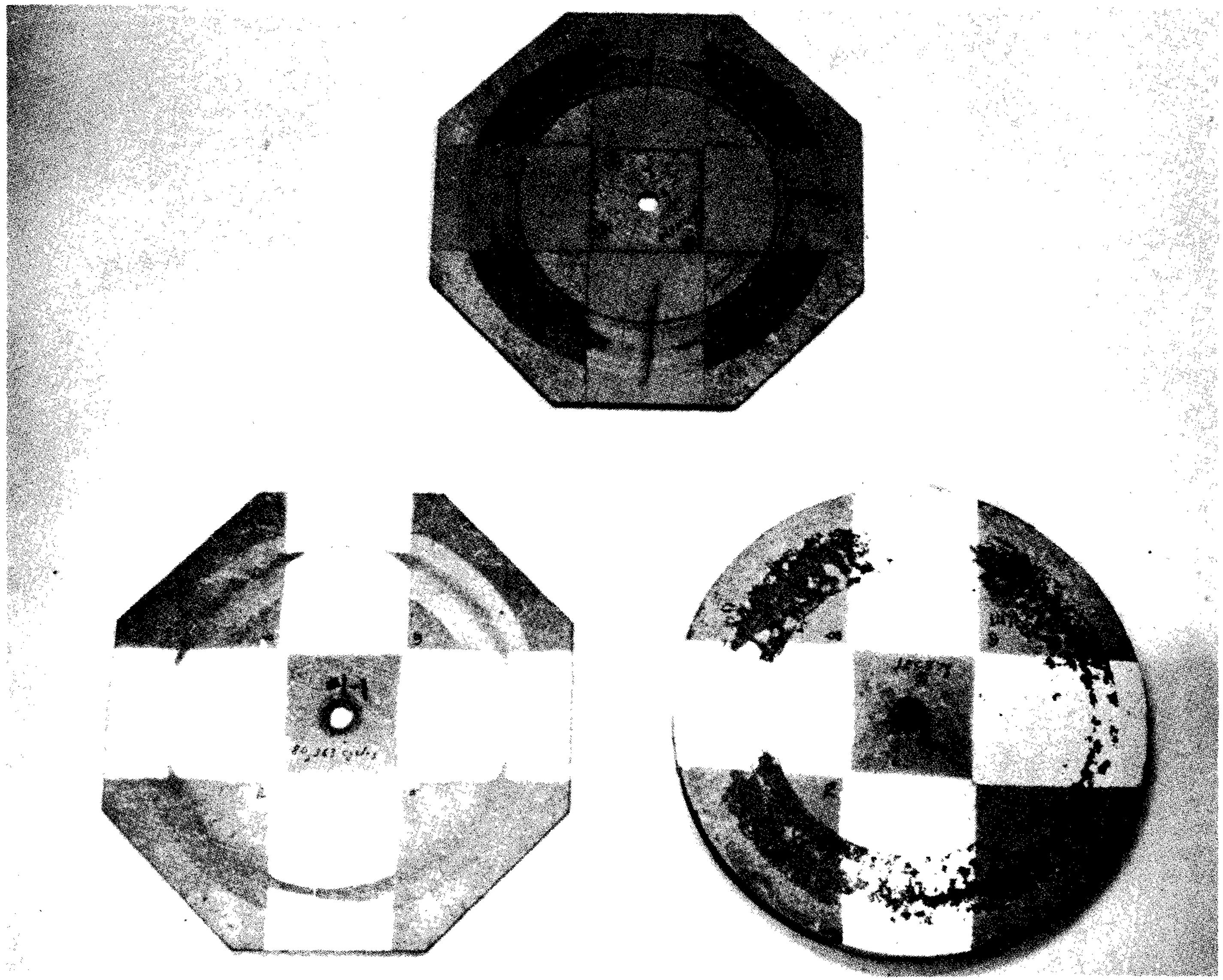

Figure 2. Wear Test Panels.

TABLE I

ABRASION TESTS OF VARIOUS PAINTS ON TRANSITE SUBSTRATE

Doctor Blade Clearance: 20 mils

Wet Film Thickness: appr. 15 mils

Paint No.	Description	Cycles to Failure* Dry	Wet
1	Ga. Yellow	+31,200	+32,300
2	Alkyd	67,900	11,600
3	Butadiene/Styrene	+70,000	15,200
4	Chlor. Rubber	+70,000	27,000
5	Lacquer	52,800	+17,000
6	Supplier's Butadiene/Vinyl Toluene	37,900	12,500
7	Supplier's Chlorinated Rubber	47,500	+23,400
8	Epoxy-Amine	+428,000	+27,000
9	Epoxy-Polyamide	+428,000	+27,000
10	Polyurethane	+104,000	+23,000
11	Ga. White	33,000	17,600

*Where a plus sign (+) precedes the value, the test was terminated prior to failure. Generally, this was done in order to preserve other stripes on the same panel as a record of comparative wear.

(3) Generally lower wear resistance in the wet condition.

E. Highway Service Correlations

The extent of correlation between the laboratory wear, and the highway cross stripe test, Series I was of primary interest. Therefore, each of the paints used on the highway tests was also subjected to the laboratory wear test wet and dry. Results from the highway tests after 7 months exposure are presented, together with the laboratory wear tests in Table II. The sense of these results is further elucidated by arranging the paints in order of rank (1-best, 9-poorest) for the tests as shown in Table III.

Note that the rank order for dry and wet lab tests are almost identical even though the wet test is more severe. The divergence between rankings of paints on concrete and asphalt highway surfaces is only slightly greater. When lab tests are compared with the highway tests, however, the correlation is seen to be generally poor. The lab tests definitely underrated the alkyd (No. 15), and the chlorinated rubber-alkyd (No. 16), and they overrated the lacquer (No. 13). On the other hand, both tests tended to substantiate high performance potentials for the "special" formulations. The urethane (No. 17) and the amine epoxy (No. 14) performed poorly on the highway, but application problems were experienced with these materials, and it was anticipated that their performance would not fully measure up to their inherent potentials.

Several shortcomings of the laboratory wear tester and procedure were apparent during the time the tests were being run, and the poor correlation with the highway tests became evident within a few months. Accordingly, plans for improving the lab test were concurrently under development.

TABLE II

LABORATORY AND HIGHWAY TEST COMPARISONS

Paint No.	Laboratory Wear Results (Count in Thousand Revolutions) Dry Count	Dry Rank	Wet Count	Wet Rank	Highway Wear Results* (7 Months Exposure) Concrete Rating	Concrete Rank	Asphalt Rating	Asphalt Rank
6	35.0	7	12.0	9	2	7	3	7
11	28.0	9	14.5	7	2	6	4	6
13	39.5	5	17.0	5	0	8	2	9
14	77^{+}	3	52^{+}	3	-	-	4	5
15	30	8	13	8	5	4	6	3
16	39	6	16	6	8	1	6	1
17	120^{+}	2	52^{+}	2	3	5	2	8
18	120^{+}	1	52^{+}	1	6	3	5	4
19	77^{+}	4	43	4	7	2	6	2

*ASTM D713-46 and D821-47.

TABLE III

PAINT PERFORMANCE RANKINGS

Rank	Paint Numbers: Laboratory Test Dry	Laboratory Test Wet	Highway Test (7 Months) Concrete	Highway Test (7 Months) Asphalt
1	18	18	16	16
2	17	17	19	19
3	14	14	18	15
4	19	19	15	18
5	13	13	17	14
6	16	16	11	11
7	6	11	6	6
8	15	15	13	17
9	11	6	-	13

III. MODIFICATIONS OF WEAR TESTER AND PROCEDURES

A. Test Substrate

As the highway tests began to mature and the nature of surface wear was observed, the vast differences in the rough character of the highway surfaces as compared with the smooth character of the laboratory cement-asbestos surfaces was strikingly evident. Even where the highway surface is relatively smooth, paint wear is first observed over exposed aggregate. Thus, the performance of a highway paint might depend largely on its adhesion and wearing qualities on an aggregate substrate. Performance on a cement-asbestos substrate could be very different, as illustrated in Figure 2. An improved simulation of the highway substrate was apparently of critical importance to the validity of the laboratory test.

Although trowelled-surface concrete discs had been abandoned as unfeasible because of gross surface variations, it seemed possible that these discs might be used if a uniform surface could be obtained. Some preliminary hand-grinding experiments yielded smooth, aggregate-studded surfaces. The results were sufficiently encouraging to warrant design and construction of a machine to face a number of the discs by grinding, so that this type of surface might be thoroughly evaluated. The disc grinding equipment and procedure are detailed in Appendix B.

B. Paint and Beading Application and Measurement

During initial experiments, spray application of paint to test panels was abandoned as excessively laborious in achieving needed precision and uniformity of specimens. The unsatisfactory results obtained with the doctor blade on the original trowelled concrete surfaces in part dictated early work on transite. Once the concrete disc grinding procedure was adopted, however, the doctor blade method for concrete became satisfactory. Subsequently, the doctor blade method yielded to a technique utilizing edge shim templates to control the clearance of a plain round draw-down bar, as described in Appendix C.1.

Adequate measurement of dry film thickness of applied paints was achieved early in the test program by use of a bridge type surface gage as described in Appendix C.3.

The importance of beading in evaluating paint performance was not fully appreciated in the early phases of the program, and much testing was performed on unbeaded films. As both laboratory and highway test data accumulated, it became apparent that beading effects must be included in the laboratory studies. At first, beads were simply sprinkled on the wet paint draw-down in quantity intended to approximate highway application at 6 pounds per gallon; however, this method was so non-uniform that results were frequently misleading. In another approach a heavy excess of beads was applied and the loose beads lightly brushed off after the paint dried. This often produced obviously unrealistic results, and a still better method was required. Uniform beading at the desired densities was finally achieved by use of a distributor device as described in Appendix C.2.

The adoption of beaded test panels for laboratory wear testing introduced a requirement for night visibility evaluations on the very small area of the test surface. In addition to other shortcomings, the Hunter Night Visibility Meter was not capable of accurately sensing the very small test area of paint in the driving wheel track on the test discs. No other suitable instrument was available; therefore, it was necessary to design a meter for this purpose. The Special Night Visibility

Meter is described in detail in Appendix D. The design of this instrument involves substantial compromises with the true geometry of highway night visibility, but the modification is justified by increased precision of measurement on a small sample. Since we understand the limitations of the instrument and use it accordingly, it serves adequately to measure relative night visibility on small areas.

C. Mechanical Features of Accelerated Wear Tester

During the several years of testing activity various mechanical features of the tester were modified to meet observed needs. These additions and changes, as discussed below, are generally in chronological order.

1. Vacuum Brush

The special eraser stock on the driving wheel created rubber buffings which tended to accumulate on the test surfaces. This problem was alleviated by mounting a vacuum brush assembly on the driving wheel to pick up the buffings before they accumulated.

2. Turntable Levelers

Before the tester was placed in service, the turntable was carefully aligned to rotate in a horizontal plane (axle vertical). It was soon found, however, that the test discs were somewhat variable in thickness so that the surface would undulate excessively under the driving wheel. This condition was corrected by installing a set of three adjustable leveling feet on the turntable to permit alignment of the disc surface into the plane of rotation.

3. Axle Pivot

In the original assembly of the machine, considerable pains were taken to align the driving wheel so that its plane of rotation was tangent to the wheel track on the test disc. After operating experience was gained, irregularities in the tread wear were observed, and it was suspected that very slight variations in tangency (toe-in or toe-out) might produce side thrusts and cause the uneven wear. This problem was corrected by mounting the rear bearing of the idler axle which supports the arm on a pivot plate which permitted the arm to swing freely in a horizontal plane. Any thrust created by misalignment of the driving wheel would then be detected by a shifting of the wheel inwards or outwards from its correct track position.

4. Shock Absorber - Wheel Loading

Beading increases the durability of paints, but is disastrous in its effect on abrasion wheels. It greatly increased the rate of wear of the driving wheel tread. In addition, it aggravated the tendency for flat-spotting to the point that treads became unuseable at a prohibitive rate.

It appeared that damping of vertical movements of the driving wheel would impart more wear on high spots and less on low spots of the tread. This self-correcting mechanism to prevent flat-spotting took the form of an automobile shock absorber installed vertically between the base of the machine and the extension on the driving wheel arm assembly. This device substantially eliminated the flat-spotting problem.

The driving wheel arm assembly was counterweighted to further reduce tread wear. A cantilever bar was attached to the driving wheel arm assembly on the end opposite the wheel and extending outward from the pivoting axle. By appropriately loading this bar, the driving wheel load could be reduced as desired.

5. Tread Stock

While uneveness of tread wear was largely corrected by damping and counterweighting, rates of wear continued to be excessive. Other types of tread stock were considered as an alternative to the special eraser stock as used by Hickson. Rubber rings of several qualities of regular automobile tire recap stock were made and tested, and the following quality was adopted as a standard:

NEW TREAD STOCK

Rubber Stock: SAF Tread Rubber (Seiberling Rubber Company)

Cured Hardness (Shore A): 70

Two difficulties were experienced immediately with the new treads; the rate of wear of traffic paints was prohibitively slow, and the painted surfaces accumulated a deposite of black gummy rubber when the machine was operated dry. The following modification was introduced to resolve these problems.

6. Abrasive Feed

The special rubber rings used in original experiments contained "built in" abrasive; the new tread stock did not. The need for an external source of abrasive medium was met by designing and installing on the machine a feeder for sand abrasive. This feeder was equipped with a timing device so that small batches of sand could be delivered to the wheel track at desired intervals.

SAND ABRASIVE SPECIFICATIONS

Source: Sewanee Silica Company, Sewanee, Tennessee

Gradation: -100 +40 mesh

Type: Clean, sharp bank sand

D. Environmental Cycling and Speed Control

During the period in which various mechanical problems were being diagnosed and corrected, laboratory wear studies under this project were confined to a uniform set of operating conditions. Thereafter, the machine was adapted to cycle the environmental variables of wetting-drying and heating-cooling in an effort to attain better simulation of service conditions. At the same time, variable driving wheel speed control was incorporated by replacing the constant speed 1/3 h.p. AC motor with a DC motor of similar size together with a motor speed controller*. The new drive provided any desired disc speed between 10 and 120 RPM.

Wetting-drying cycling was accomplished by supplying water to the test disc through a copper tubing system containing a solenoid valve controlled by a continuously recycling timer. The on-off cycles were accurately controllable within any desired time limits.

Heating and U.V. irradiation was provided by a pair of 250 w. sunlamps mounted directly above the test disc. A rapid cooling effect was produced when water was admitted to the disc after a drying period, so that on-off cycling of the lamps did not appear to serve any useful purpose and was not incorporated in the design.

Much experimentation was required to establish appropriate lamp spacing and wetting-drying cycles. The lamps were eventually located at 9 inches above the disc. Under these conditions, following a period of water soaking, a test disc would return to a surface dry condition in about 5 minutes and rise to a temperature of about 120° F in 30 minutes. A typical drying-heating curve is shown in Figure 3. The cooling rate curve was not determined experimentally, but at the normal water flow

*Boston Gear Speed Control, Catalog No. R-33 with 1/3 H.P. DC motor, 1750 R.P.M.

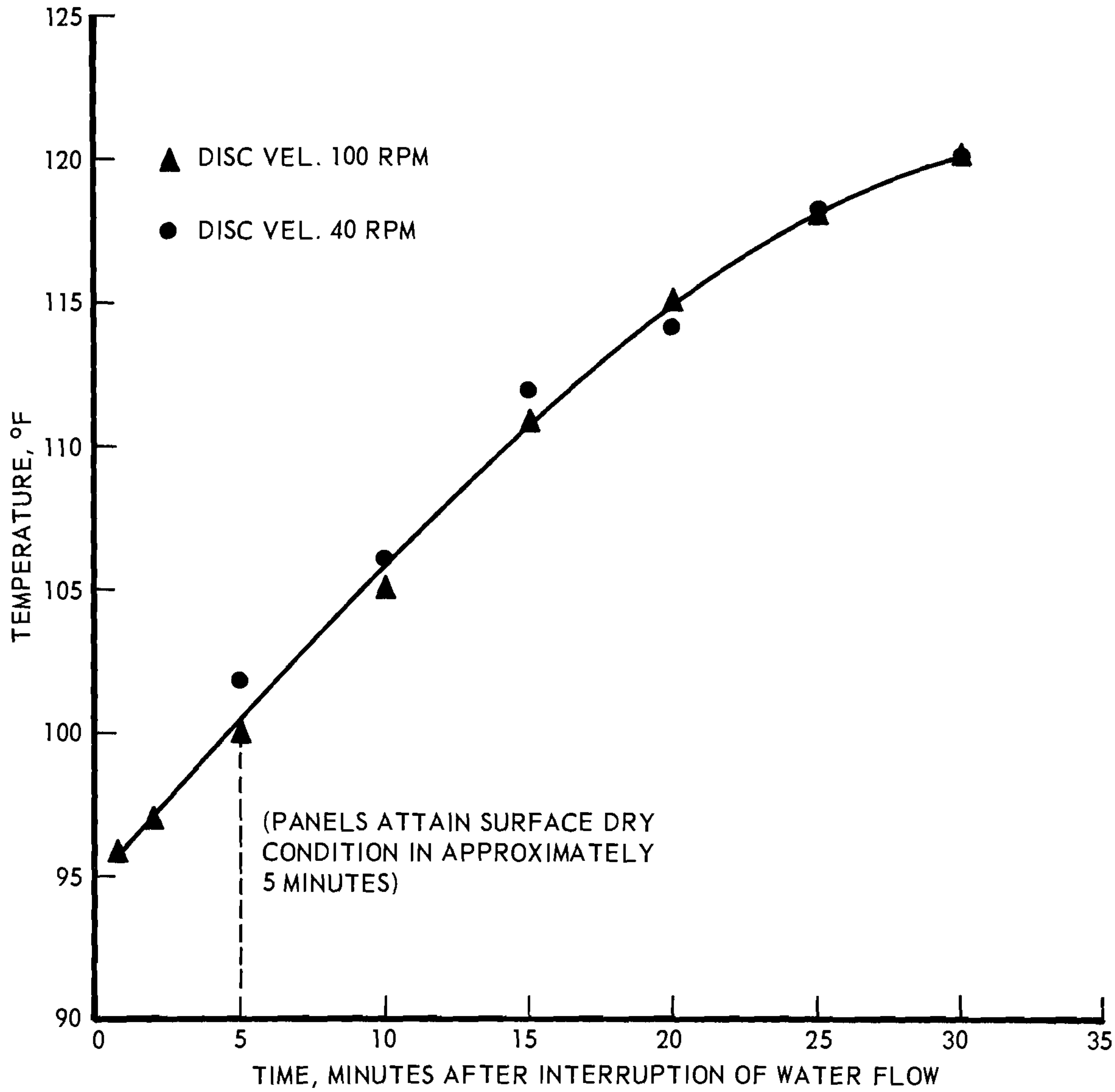

Figure 3. Drying-Heating Curve.

rate of 100 cc/min., the disc surface was observed to return from dry equilibrium to approximately water temperature very rapidly. The tendency of the new rubber treads to impart a black gummy deposit to the painted surfaces when operated under dry conditions has been previously mentioned. This tendency imposed limits upon the feasible cycling conditions of the wear tester. The external abrasive supply partially alleviated the problem, and no deposition occurred under wet conditions. Beyond this there was no recourse except to adapt to the capabilities of the available tread. Fortuitiously, satisfactory operation was attainable within the imposed limitations.

The major shortcomings of the original machine had now been surmounted, and intensive experimentation was undertaken to explore the operating variables on the considerably modified accelerated wear tester. Simultaneously, highway test results were maturing and were being examined in relation to the accelerated wear test. Together, these studies not only led to a better understanding of limitations of both highway cross-stripe tests and the laboratory tests; they also suggested a new approach to laboratory testing. These matters are discussed in the next section.

IV. FINAL EQUIPMENT AND TESTING CONDITIONS

A. Wear Tester Design and Testing Concepts

The numerous equipment design modifications have been detailed in Section III, and the final machine is shown in Figure 4. The operating variables, operating limits, and nominal levels are given in Table IV. While the modified tester is capable of almost unlimited combinations of operating variables, both theoretical and practical considerations impose marked limitations on the combinations that are worthy of study.

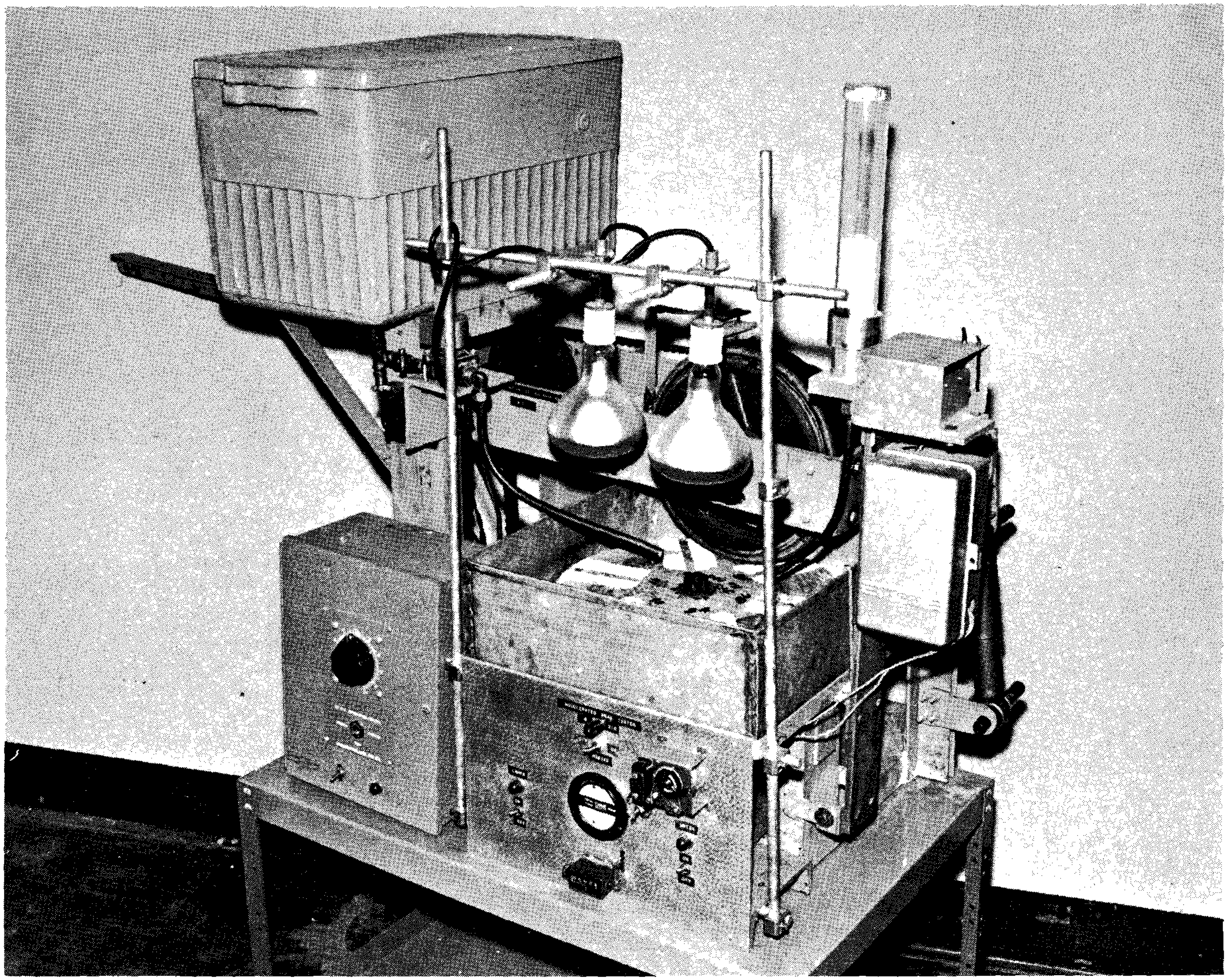

Figure 4. Final Wear Test Machine.

TABLE IV

OPERATING VARIABLES OF ACCELERATED WEAR TESTER

	Variable	Operating Limits Minimum	Operating Limits Maximum	Nominal Levels (s)
1.	Driving Wheel Load, lbs.	0	-	40
2.	Disc Speed, RPM	10		40, 100
3.	Abrasive feed, g/hr	0		0, 17
4.	Water feed			
	Continuous rate, g/min.	0	-	100
	min. Cycle:			
	On, %	0	100	
	Off, %	0	100	
5.	Lamps, position above disc, inches	0	-	9

Ideally, one would wish to choose a set of operating conditions to closely simulate an actual set of highway service conditions, and thereby hope to obtain analogous results. In practice, this approach has appeared to be unfeasible. In the first place, no reliable means has been developed to define a particular set of highway conditions in quantitative terms. Secondly, despite the considerable elaboration of environmental simulation on the laboratory tester, the device is inherently incapable of simulating tire-surface dynamics on high-speed expressways. (This particular limitation is discussed further in Section VII.)

The reader will recall that, in Part II of this report, the alkyd control paint (No. 15) was found to exhibit different modes of failure in different test series (erosion - Series I, chipping - Series II and III). If undetected differences in the highway environment can yield such large performance differences, obviously, no single laboratory test can be expected to correlate with highway performance. A better approach to laboratory testing may be to attempt to examine at least two sets of environmental conditions, and by these tests detect the comparative performance limitations of a paint. More specifically, if a paint may fail by either erosion-abrasion or chipping-adherence loss, one may test separately for failure by each of these mechanisms. This dual approach was taken in the final studies on the accelerated wear tester. Also, in view of the apparently extensive effects of the uncharacterized variable of "surface condition" during the highway studies, some laboratory experimentation was directed at further elucidation of this factor.

B. Development of Standardized Operating Conditions

By adopting a dual approach, we considerably narrowed the appropriate range of operating conditions for each of two types of accelerated wear tests. Much testing to establish standardized conditions followed. Table V presents several sets of operating conditions which were studied in sufficient detail to permit a general characterization of each. Among the six operating conditions included in these studies, Condition II would be most useful for evaluating erosion resistance and night visibility loss. Condition V is best for evaluating adherence-chipping resistance. Normally, a paint should be tested under both conditions. For certain formulation development work in which interest is directed at only a single performance attribute, a single test condition may suffice; thus, if interest were directed solely at erosion resistance, Condition I is usually capable of providing an evaluation within 2 to 6 hours.

The foregoing standardization of operating conditions covers only a small sampling of possible combinations within the present capabilities of the machine; however, it is doubtful that a more exhaustive exploration would prove fruitful, for the following reasons:

1. The driving wheel load cannot be reduced below 5 pounds without excessive loss of driving contact; at levels above 40 pounds rubber begins to deposit excessively. Within these limits, paint performance is not highly sensitive to loading.

2. Disc speeds of 10 RPM are so slow that dynamic effects become trivial. Above 100 RPM, vibrations begin to become excessive, and stable operating is difficult to maintain. Intermediate speeds serve to control the intensity of dynamic and abrasive effects, so that environmental cycling may contribute appropriately to the test system prior to failure.

3. Abrasive feed should not be considered as a continuous variable. Abrasive must be delivered so as to provide uniform

TABLE V

STANDARDIZED OPERATING CONDITIONS

Variable	Operating Condition I	II	III	IV	V	VI
Driving Wheel Load, lbs.	40	40	40	5	40	5
Disc Speed, RPM	100	40	10	100	100	40
Abrasive Feed, g./hr.	17	17	none	none	none	17
Water Feed, 100 g./min.						
On, min.	Continuous	20	5	5	5	20
Off, min.		10	25	25	25	10

Characterization

Condition I. Very rapid erosive failure. Night vis. cannot be observed.

II. Moderate erosive failure. Night vis. observable as a function of time.

III. Extremely slow (200 hrs.) failure by cracking, spalling, chipping.

IV. Used primarily with discs wax impregnated to reduce adhesion. Cracking, spalling, chipping failures initiate in 10 to 20 hrs.

V. Achieves some acceleration over Condition IV. Particularly indicated for use with unimpregnated discs which are more resistant to adherence failure.

VI. Variation of Condition II yielding slightly slower erosive failure.

abrasive conditions without excessive build-up on the disc. When interest is directed at adherence-chipping, no abrasive can be used because erosion invariably precedes and precludes the phenomenon of interest.

4. Water feed and lamp spacing serve to define the environmental variables. The lamps were spaced, as described earlier, so that disc surface temperatures would never exceed about 130° F. The water flow rate was adjusted to provide a fairly rapid wetting-cooling effect on a dry disc without producing a heavy flooding of the surface. Water on-off cycling was adapted to other operating objectives. In the case of erosive studies, wetness and flow enhances uniformity of abrasive action; therefore, 20 minutes on and 10 minutes off yields a maximum period of wetness and flow consistent with retaining at the same time the environmental cycling. Conversely, maximum shearing stresses are imparted to a dry paint film. Thus for adherence-chipping evaluations a 5 minutes on and 25 minutes off cycle emphasized the desired mechanism without eliminating environmental cycling.

V. FINAL SYSTEMATIC STUDIES

Having devoted the major portion of our laboratory work to a lengthy series of experiments, from which evolved a greatly modified wear test machine, with test procedures and associated equipment tailored to meet the needs of that machine, we now turned our attention to a final set of experiments utilizing this facility. It would be erroneous to assume that in these particular final tests we realized the ultimate capabilities of the equipment for evaluating traffic paints. However, the experience we had accumulated suggested that further elaboration of the device and procedures would not be indicated until such modifications would be based on valid fundamental considerations.

A. Paints

All of the paints included in the final systematic tests are proven formulations of high quality; consequently, the absence of large performance differences may not be interpreted as reflecting lack of sensitivity on the part of the laboratory wear tests. Paints of decidedly poor quality are readily detected by less sophisticated devices, as they were even in the earliest experiments in this program. In a program that purports to classify the "sheep," nothing useful can be gained by including the "goats."

Descriptions and Paint Numbers of the items included in these studies are given below:

PAINTS FOR FINAL TESTS

Description	Paint Number
Standard Alkyd	90
Chlorinated Rubber-Alkyd	84
Epoxy Ester	88
Butadiene/Vinyl Toluene	86

Formulations of each of these paints are detailed in Part II, Appendix A, of this report.

B. Description of Experiments

Five sets of experiments, all with the same paints, are reported hereunder. The first four were designed to provide data for correlation with highway tests. The fifth set was designed to reveal some effects of substrate variations. Experimental test conditions are summarized in Table VI.

TABLE VI

SUMMARY OF TEST CONDITIONS

Test Set	Operating Condition*	Disc No.	Substrate	Surface Treatment	Nominal Film Thickness, mils
1	II	85	Concrete	None	10
		83			15
		84			20
2	VI	94	Concrete	None	10
		96			15
		98			20
3	III	82	Concrete	None	10
		86			15
		87			20
4	V	103	Concrete	Waxed	10
		104			15
		105			20
5	V	106	Transite	None	15
		110		Waxed	15
		111	Ground Glass	None	15
		112		Waxed	15
		107	Polished Glass	None	15
		113		Waxed	15

*See Table V. Conditions II and VI, utilizing abrasive, differ in Driving Wheel Load (II = 40, VI = 5 lb.). Conditions III and V, without abrasive, differ in Disc Speed (III = 10, V = 100 rpm).

C. Disc Preparation Procedures

1. Conventional Concrete Discs

Test sets 1, 2, and 3 involved use of conventional concrete discs and preparation procedures as described in Appendixes A and B.

2. Surface Treated Discs

Surface treatment of discs to reduce the level of paint adhesion was utilized in test sets 4 and 5. The treatment was accomplished in all cases by soaking the panels thoroughly in a 4% solution of micro-crystalline wax (Shellwax No. 500) in toluene, draining off the excess, and allowing the coating to air dry several hours. Subsequent paint application to these discs was identical with conventional discs.

3. Special Substrates

The special substrates investigated in Test Set 5 included plate glass, ground glass, and transite, each with and without the wax treatment. The plate glass was used "as received." The ground glass was prepared by manually grinding the plate glass surface to a uniform texture with silicon carbide #60 abrasive. The smooth side of the transite was used as the test surface "as received."

D. Test Results and Data Reduction

Original test data on all test sets are tabulated in Appendix E. As in previous studies, paint integrity is reported on the ASTM scale based on photographic standards of ASTM D-821-47 erosion and D-913-51 chipping. Night visibility is reported based on the Special Night Visibility Meter readings. The following data reduction procedures were performed to aid in interpretation.

1. Test Sets 1 through 4

As shown in Table VI, each test set of this group consists of three discs. Each disc contains four test paints at the nominal thickness indicated. The first step in the correlation procedure, identical with that described in Part II for the highway studies, was to extract relative performance parameters for each paint on each disc. Thus, integrity values for each paint were determined at the time the control paint exhibited a value of 5, and night visibility values were determined when the control paint exhibited a value of 10 on the Hunter Meter. All night visibility data was taken with the Special Reflectometer (Appendix C), but was converted to equivalent Hunter readings. Finally, the resulting individual performance parameters for each paint were averaged over the three discs in each set. Accelerated Wear Test data in this form may then be compared with corresponding data from the Highway Test Series as shown in Table VII. It is appropriate to emphasize again that every number in the table is an average based on independent observations of at least three individual test discs or highway cross-stripes.

2. Test Set 5

The results of this study of special substrates do not lend themselves to direct correlation with highway tests; rather, they serve to illustrate the magnitude of the effects of substrate variations on paint performance. On many of these test discs the paints were observed to undergo almost no change for an "induction period" and then tend to fail rapidly and catastrophically in the spirit of the legendary "One Horse Shay." Accordingly, the induction period appeared to be the best parameter for characterizing substrate performance. More specifically,

TABLE VII

ACCELERATED WEAR VERSUS HIGHWAY TEST RESULTS

Paint Nos.	Type	Accel. Wear Test							Highway Tests					
		Integrity				Night Vis			Integrity			Night Vis		
	Condition	II (Eros)	VI (Eros)	III (Chip)	V (Chip)	II (Hunter	VI Equiv)	Series	I (Eros)	II (Chip)	III (Chip)	I (Eros)	II (Chip)	III (Chip)
15, 90, 92	Std. Alkyd	5	5	5	5	10	10		5	5	5	10	10	10
16, 36, 84	Chlor. Rub.-Alk.	8	8	10	8	14	11		8	8	5	7	11	15
6, 86	Butadiene/VT	8	8	10	2	14	14		3	-	3	2	-	4
88	Epoxy Ester	6	8	10	5	13	10		-	-	5	-	-	16

the induction period is defined as the time required for at least one paint on a disc to reach an integrity reading of 5. On this basis, data from test set 5 is summarized in Table VIII.

E. Correlation and Analysis

1. Accelerated Wear vs. Highway Tests

The value of the dual conception of the accelerated wear test, which involves separate evaluations of erosion and chipping tendencies, may be readily appreciated by reference to Table VII.

a. Integrity Evaluations. Note that Test Condition II in the lab test corresponds very closely with Series I on the highway, except in the case of the Butadiene/VT paint. References to the Project Notebook (No. 1407, p. 76) show that a chipping mode of failure was recorded for this paint in Series I, even though erosion prodominated among most of the test paints. This susceptibility to chipping is reflected in lab Test Condition V. Series II and III involving chipping failure on the highway also correspond closely with lab Test Condition V. Thus the laboratory-highway correlation of paint integrity is quite good. In short, Test Conditions II or VI may be used to measure erosion, and Test Condition V to measure chipping. Condition III is inferior to V for chipping measurement.

b. Night Visibility Evaluation. Because of the small-scale operation, techniques for application of beading and for measurement of night visibility could not be controlled with the desired degree of precision, either in the laboratory or on the highway. In spite of this restriction, it is gratifying to observe a general correspondence of lab

TABLE VIII

ACCELERATED WEAR TESTING* - SUBSTRATE EFFECTS

Disc No.	Substrate	Time of Test, Hrs. and ASTM Rating** Std. Alk. #90	Chl. Rub.-Alk. #84	Epox. Est. #88	S/B Resin #86
86	Concrete***	102 (4)	102 (9)	102 (9)	102 (9)
104	Concrete, wax treated	4 (7)	4 (9)	4 (6)	4 (2)
107	Plain Glass	9 (1)	9 (5)	9 (5)	9 (10)
113	Plain Glass, wax treated	1 (5)	1 (10)	1 (9)	1 (10)
112	Ground Glass	21 (1)	21 (9)	21 (9)	21 (9)
111	Ground Glass, wax treated	1 (4)	1 (10)	1 (10)	1 (9)
106	Transite	110 (10)	110 (10)	110 (8)	110 (9)
110	Transite, wax treated	3 (5)	3 (2)	3 (1)	3 (4)

* Test Condition V. (Wheel load - 40 lbs., Speed - 100 RPM, no abrasive.)

** ASTM Integrity Rating is in parenthesis.

*** Test Condition III. (Wheel load - 40 lbs., Speed - 10 RPM).

Conditions II and VI with highway Series II and III. The butadiene/VT paint appears at first to be a maverick in the lab tests, probably because lab Conditions II and VI do not measure chipping, which is a sufficient cause for the low values in highway Series I and III (Highway Series I might be appropriately disregarded in this matter, because of serious deficiencies in beading technique). However, with proper allowance for chipping failure, Test Conditions II or VI correspond well with highway Series III. Even if the deliberate wheel loading variation between Conditions II and VI be ignored, the reproducibility of the lab tests is seen to be superior to the highway series.

2. Special Substrates

In selecting surfaces for this special study, the goal was not so much to remain within the realm of the realistic as to gain the advantage of sharp definition. Materials were selected for certain characteristics, appropriately interpreted in the following terms:

Plain glass - impermeable, smooth
Ground glass - impermeable, slight roughness
Transite - permeable, smooth
Concrete - varying permeability, varying roughness

Duplicate discs of each were run, with and without a wax treatment. The wax treatment obviously inhibits adhesion in all cases; in addition, it renders the transite and concrete less permeable.

Table VIII shows the test period and ASTM ratings of the four coatings on these surfaces. The more severe test conditions on bare concrete are not identical with those in the balance of the table; nevertheless, the reported testing time of 102 hours can be safely assumed to be longer than the standard condition would yield.

Direct conclusions are virtually self-evident in the table and justify the following generalizations:

1. Waxy contamination affects chipping resistance (adhesion) of traffic paints catastrophically on any substrate. In highway striping, deposits of oil droppings, accumulating over a period of time, would exert a similar effect.

2. Smooth, impermeable substrates provide very poor chipping resistance, but some improvement is achieved by imparting surface roughness. Most exposed aggregate surfaces on the highway would be impermeable, with a degree of roughness.

3. Smooth permeable substrates exhibit dramatically superior adhesion. This type of surface has no close parallel on highway surfaces, but the mortar matrix of concrete exhibits a permeability that undoubtedly promotes adhesion.

4. The chipping performance of concrete (which exhibits exposed aggregate surfaces) is consistent with a conception that surface characteristics of permeability and roughness are additive in their effects.

VI. SUPPLEMENTARY STUDIES - PHYSICAL CHARACTERIZATION TESTS

A. Purpose of Studies

Prior phases of this investigation of traffic paints have been concerned with paint formulation, with evaluation of highway performance, and with accelerated laboratory evaluation of performance by simulation-type testing. This work led to some qualitative impressions about the relations of certain basic properties of paint films to practical performance; however, our ultimate concern in a study of this nature is the quantitative relationship between the basic properties of a paint and its performance. This is the rational approach to the development of improved paints. These supplementary studies - physical characterization of those formulations for which performance parameters have been determined - constitute the concluding experimental phase of this work.

The selected test methods are quantitative, with the single exception of pencil hardness. The latter has been correlated with quantitative methods by Smith 5/. The principal difficulty has been that of relating these test results to fundamental mechanical properties and to performance; however, some pregress has been made even in this direction.

B. Test Methods

1. Selection of Tests

Test methods were chosen to evaluate the primary aspects of mechanical behavior of films. Detailed procedures for the following methods are presented in Appendix E.

a. Static stress-strain properties were characterized by the conical mandrel flexibility and pencil hardness tests. Conical mandrel flexibility (per cent elongation) at break indicates the elongation of the film at loadings exceeding the ultimate strength of the film. Pencil hardness was regarded as representing the stress at which the film ceased to exhibit elastic behavior (yield stress). The latter has been related to the numerical scales of the Tukon and Sward tests 5/.

b. Adhesion of film to substrate was measured by the angular scribe-stripping technique. This technique yields a dimensionless adherence number by which adhesion of paints can be quantitatively related.

c. Impact deformation at break was characterized by the reverse impact test, in which the substrate is deformed by progressively increasing impact loads until the film fails.

Tests were performed on conventional equipment, since test development work was not feasible. Conventional tests, performed on equipment which is widely available and familiar to many investigators, have the added advantage of yielding results which are readily comparable among laboratories. An exception to the rule of wide familiarity was the measurement of adhesion by the angular scribe-stripping technique. This test, which was previously developed in this laboratory, has the special virtue of providing quantitative, rather than qualitative, results.

A principal disadvantage of many conventional paint tests is that basic properties are not measured independently. Test results tend to confound the principal parameter with other variables. It is frequently difficult to definitely identify the variables which affect a result. The tests selected for these studies are believed to provide a measure of independence which, with appropriate reservations, permits them to be treated as primary parameters.

2. Selection of Conditions

a. Substrate. All tests of mechanical properties were performed on cold-rolled steel. In the first place, the mandrel flexibility and reverse impact tests require readily deformable substrates and the bulk of previous experience with the angular scribe-stripping technique has been on metal surfaces. In the interest of uniformity of film conditions the same test panel used for the other tests was also used to measure pencil hardness.

In the second place there is reason to believe that test results over steel would be ordered similarly, and probably would have the same relative values, as test results over concrete (supposing the tests could be performed on concrete). Substrate differences affect adhesion more than any other parameter. Adhesion in turn affects all the tests to some degree. Current knowledge indicates that the adhesion for any given paint is dependent mainly on substrate surface energy. Concrete surfaces and the multi-molecular oxide surfaces which cover the steel are both comparatively high-energy surfaces.

A significant difference between steel and concrete surfaces is that concrete presents a heterogenous surface to the paint. Thus adhesion would be expected to be more variable from point to point on concrete. For the purposes of testing, however, it was assumed that an average adhesion due to surface energies would affect test results very much the same way on steel as on concrete.

b. Film Conditions. Special interest was directed to the effects of film ageing on physical properties. Accordingly, paint films were tested both in an initial (air dried 7 days) state, and after subjection to a period of mild heat ageing (24 hours @ 80° C) following the initial air drying.

C. Results

Film characterization test results are presented in Table IX.

D. Observations

The test results presented in this study are based on limited replications, and efforts to interpret minute differences among the several paints cannot be justified.

TABLE IX

PHYSICAL TESTS OF HIGHWAY PAINTS

Paint No. and Type	Film* Condition	Pencil** Hardness	Adherence No.	Conical Mandrel Test (Elongation at Break, %)	Reverse Impact Test in.-lbs.
90	A	< 5B	3.0	13.8	8
Std.	O	H	2.3	8.2	8
Alkyd	Change	+> 7	-.7	-5.6	0
84	A	< 5B	10	7.1	4
Chl. Rub.	O	F	3.8	7.1	14
Alkyd	Change	+> 6	-6.2	0	+10
88	A	< 5B	8.5	11.6	26
Epoxy	O	F	20+	8.2	26
Ester	Change	+> 6	+11.5+	-3.4	0
86	A	5B	7.6	10.5	4
B/VT	O	H	2.1	5.8	2
Resin	Change	+7	-5.5	-4.7	-2

*Film Condition:
A = Air dried 7 days
O = Air dried 7 days, then baked 24 hrs. at 80° C.

**Test pencils increase in hardness in the order: 5B, 4B, 3B, 2B, B, HB, F, H

Without any qualification, the results show clearly that the oven ageing process produces significant changes in all paints. These changes are reflected most consistently by an increase in pencil hardness, which may also be interpreted reasonably as an increase in the yield stress of the films. The other tests, with minor exceptions, suggest that oven ageing causes embrittlement and loss of adhesion.

The initial and final hardness of the butadiene/VT paint (#86) is slightly, but significantly, higher than the other paints. Ageing of this paint produces low values for adherence number, elongation, and reverse impact. This consistent pattern of response is compatible with the relatively poor chipping resistance of this paint on the accelerated wear tester and on the highway.

Superior adhesion and impact test values for the chlorinated rubber-alkyd (#84) and the epoxy ester (#88) are compatible with highway observations of enhanced bead-binding (night visibility) characteristics of these paints.

With a few exceptions, the several paints exhibit a rather narrow range of test properties; they are not markedly different in physical characteristics. This is consistent with their generally similar performance on the accelerated tester and on the highway.

One notes, finally, that since ageing effects are substantial and the accelerated wear tests are performed upon unaged films, the tester may not be capable of accelerating ageing at a rate that would parallel the accelerated mechanical wearing effects. This would suggest that a pre-ageing of accelerated wear test discs might be considered as a further refinement of this procedure.

VII. THEORETICAL ASPECTS OF TRAFFIC PAINT PERFORMANCE

The previous sections of this report exemplify the pragmatic approach of purely empirical experimentation and correlation that has characterized paint studies in the traffic field as in most other areas of application. While this approach is effective in accomplishing narrowly defined objectives, it does not supply the theoretical framework that is needed to achieve major advances in formulation technology. However, empirical experimentation often serves to stimulate the investigators into digging deeper into the fundamentals of a problem. It was just such a stimulus that led to the theoretical treatment given in this closing section of the report.

This treatment has two objectives. First, it is intended to bring to the surface some of the factors underlying the phenomena of wear observed in the course of these studies and to provide thereby a much clearer conception of the nature of traffic paint failure. Second, it provides a tentative working theory for further studies of traffic paint wear, from which sound engineering design principles may evolve.

There is no attempt to be completely rigorous throughout or to arrive at end results that provide irrefutable means for correlations and predictions in traffic paint wear. But a path is laid out, and a start is made, with confidence that further exploration will eventually lead to such end results.

The empirical studies reported herein show clearly that traffic paint failure falls into two distinct types. Abrasion-erosion has received theoretical treatment by others; consequently, it is reviewed only briefly. Primary attention is given to the phenomenon of adhesion-chipping failure, and means are indicated for correlation with the standard rate equation. Experimental test methods and data are then reviewed in the light of the theoretical results.

A. Abrasion-Erosion

1. Source of Abrasive Action

The wear patterns of traffic paint cross-stripes show conclusively that weathering effects may be discounted as a factor in the failure mechanism of quality paints and that mechanical wear, caused by tire action and aggravated by sand or other particulate matter, is the prime source of abrasive failure of traffic paint.

2. Mechanics of Abrasion

Abrasion may be conceived of as the summation of a large number of individual interactions between the paint and the tire in which the paint is pulled apart and separated at the surface. Each of these interactions involves a quantity of work which can be characterized by a stress-strain curve, and the summation or total abrasive effort may be expected to correspond approximately to the total area under the stress-strain curve characteristic of the paint. The validity of this correspondence has indeed been demonstrated experimentally by tests utilizing grit-blast abrasive techniques 6/.

The energy input required to produce abrasive failure must be equal to the energy output represented by that failure plus all energy losses, which would be manifested primarily as heating effects. These heating effects, if not negligible, would at least be fairly constant. It follows that the abrasion resistance of a paint film should be approximately proportional to the cohesive energy (W_c) of that film, which may be expressed as the area under a stress-strain curve; thus,

$$\text{Abrasion Resistance} \cong KW_c = K\int_0^{s_u} s\,de$$

where:

W_c = work of cohesion

s = stress

s_u = ultimate stress

e = elongation

K = a constant

A typical paint stress-strain curve is shown in Figure 5. A statically determined curve may not be representative of dynamic conditions, as the stress-strain curve of a material will generally change with the rate of loading. The usual effects of increased rate are an increased stress level and reduced elongation. Under these circumstances, a useful approximation to the value of the integral is obtained by writing:

$$\text{Abrasion Resistance} \simeq Kse$$

Abrasion resistance may be correlated with the work of cohesion only for solid materials which possess a definite ultimate stress under service conditions. Certain thermoplastic materials may act as viscous liquids and deform without limit; such coatings are characterized by their deformation and flow, and abrasion resistance is simply not an applicable characteristic. A comprehensive study of abrasion phenomena has been presented by Bitter 8/.

B. Adhesion-Chipping

1. Source of Adhesion-Chipping Failure

The principle factors affecting traffic paint adhesion are thermal-environmental effects and dynamic mechanical effects. The former may never be totally ignored, and may in some circumstances be the controlling factor of paint performance. A quantitative development of these

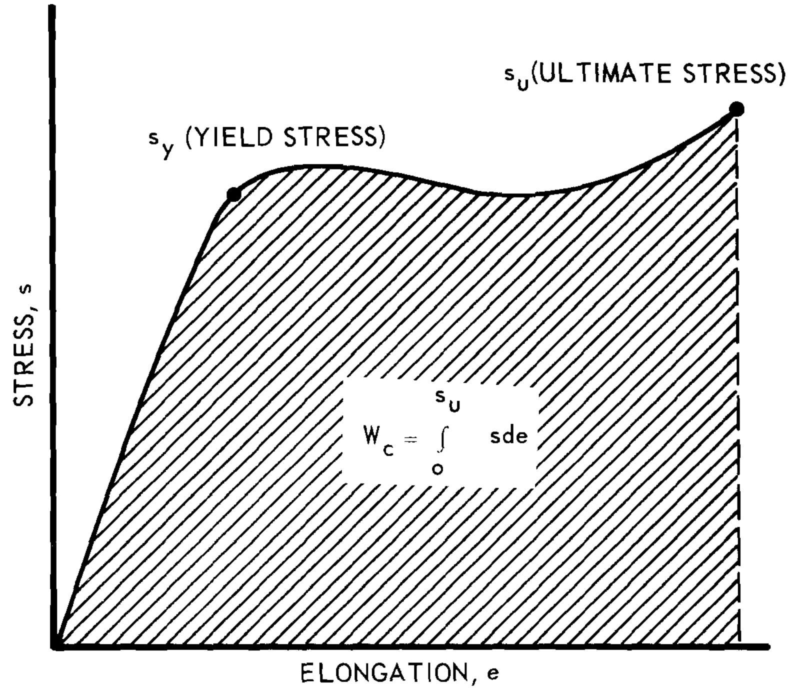

Figure 5. Paint Stress-Strain Curve.

factors will not be undertaken here, but qualitatively we will observe that differences in thermal and moisture coefficients of expansion and contraction impose tensile stresses on paint films and bond stresses at the interface which may eventually exceed the ultimate strength of the film. 7/ When these conditions are further aggravated by freeze-thaw movement, some film failure is inevitable. These thermal-environmental effects are well-understood and could be developed in more analytical detail if desired. Major attention is directed to a quantitative treatment of dynamic-environmental effects, which we believe to be the dominant factors in the chipping failure of quality traffic paints on high speed expressways.

2. Dynamics of the Tire-Road Surface Contact

When a tire rolls over a surface, it compresses air ahead of its physical contact, imparts downward pressure over the area of tread-surface contact, and creates an area of low pressure (partial vacuum) along the line of partition. The overall effect is that of a pressure wave sweeping across the surface. While this pressure wave has but a single cycle, it is characterized by a frequency, or period, determined by the velocity of the vehicle, the radius of the tire and the length of contact surface between tire and roadway. Its amplitude is proportional to the inflation pressure of the tire. Even with a conservative assumption that the average tire inflation pressure is only 28 psi, if the wave length is taken to be 8 inches ($\frac{\lambda}{2} = 4''$), then the average rate of pressure change at 60 mph would be 7400 psi/sec. Thus, highway surfaces are subjected to very high speed impact loads at substantial pressures.

A complete discussion of the dynamic forces on traffic paint films must also include the lateral and transverse forces imparted by acceleration and deceleration of vehicles. The magnitude of these forces can be very large under appropriate circumstances. For example, if a 4000 pound vehicle is accelerating at a rate of 9.8 ft/sec^2 the reaction force is

$$F = \frac{Wa}{g} = \frac{4000 \times 9.8}{32.2} = 1210 \text{ lbs.}$$

If the total traction surface is 70 in^2 then the average shearing stress on the paint surface would be

$$S = \frac{F}{A} = \frac{1210}{70} = 17.6 \text{ psi.}$$

This stress would produce tensile stress and deformation of the film in the surface plane and would also be transmitted as a shearing stress at the paint bond.

These effects are undoubtedly of major practical significance for traffic lines placed at street intersections. They are also pertinent to accelerated wear testing designed for adhesion-chipping evaluations (Conditions III and V). On open highways, however, accelerations and decelerations are less intense and frequent, so that this mechanism must be regarded as distinctly secondary to the pressure wave mechanism as the causative factor for adhesion-chipping failures.

3. Mechanics of Film Adhesion-Chipping Failure

If traffic paint films were firmly bonded at all points to a continuous substrate, then loads of the magnitudes described above would not subject the film to seriously destructive stresses. But, the concrete substrate is in fact rough and discontinuous. The paint must bridge over holes and crevices, tar spots, grease films, dirt and dust.

The theory of film failure by disbonding and film rupture is based upon the practical conceptions that unbonded or unsupported areas exist in the film, that these areas may be present initially or may develop subsequently under paint films, and that pressures are imparted by tire action. The geometric model* for the theoretical development is shown in Figures 6 and 7, representing cross-sections of a "blister" of paint in the form of a hollow spherical segment bonded to the rigid substrate at the periphery of its base. The deformation of the blister has been exaggerated to permit a clearer display of the geometrical parameters.

The following explicit assumptions are made:

1. The paint film is a mechanically homogenous membrane.

2. Deformations are within the elastic limits - progressive film failure occurs when yield stresses are exceeded.

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*All mechanical theories require precisely defined analytical models. The test of validity of the model is not how closely it appears to physically simulate the phenomena of interest, but rather, how effectively the developed theory correlates experimental data. While we will present later some evidence which tends to support this model, we would hasten to emphasize that the more important purpose of this development is to demonstrate a method of attacking the problem rather than to indulge in varied modeling conceptions. It will also become evident from the following analysis that simplicity of modeling is a virtue if not a mathematical necessity.

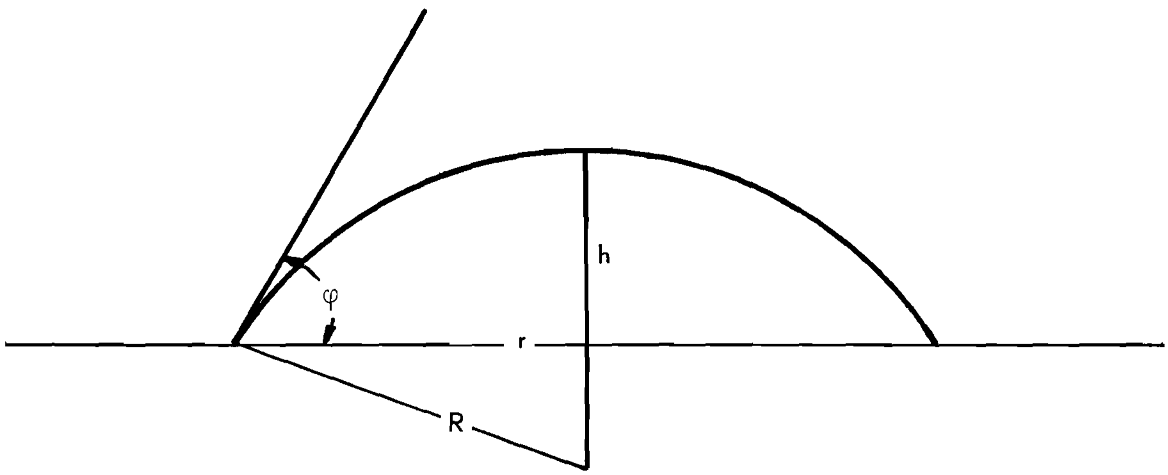

Figure 6. Geometric Representation of Film "Blister".

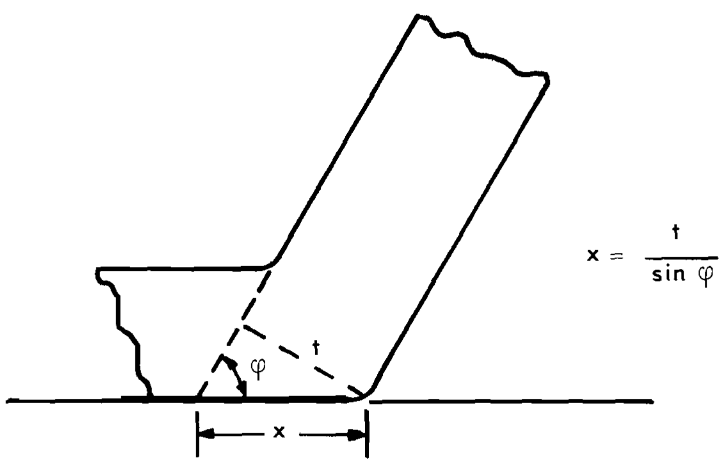

Figure 7. Effective Film Bonding Width.

3. Flexural stresses within the film are negligible; the thickness of the film is small relative to the blister radius.

4. Application of fluid pressure against the unbonded film disc expands the film into a spherical segment shell.

5. The work done on the film disc by the fluid pressure is uniform over the area of the disc.

A solution of the force equilibrium equation ($\Sigma F_y = 0$) for fluid pressure yields the following expressions:

$$P = \frac{2ts_c \sin \varphi}{r} \tag{1}$$

$$= \frac{2ts_b}{r \sin \varphi} . \tag{2}$$

where:

P = fluid pressure expanding the film disc into a spherical shell

t = film thickness

r = blister radius

φ = blister-substrate intercept angle

s_c = tensile (cohesive) stress in film at periphery

s_b = bonding (adhesive) stress between film and substrate

The maximum pressure that the unbonded film will sustain is given in Eq. 1 and 2 in terms of the tensile and bonding yield stresses, respectively. If either yield stress were exceeded, progressive failure would ensue. Note that sin φ is a film deformation parameter and its effect is in opposing directions for adhesion and cohesion. These relationships may be more clearly elucidated by a plot of required minimum yield stresses as a function of sin φ. As a practical example let us assume that

$$\frac{Pr}{2t} = \frac{16 \text{ psi} \times 0.5 \text{ in}}{2 \times 0.010 \text{ in}} = 400 \text{ psi}.$$

Thus

$$s_c = \frac{400}{\sin \varphi} \text{ psi}, \qquad s_b = 400 \sin \varphi \text{ psi}.$$

Figure 8 is a presentation of the results. Since cohesive stress approaches infinity as sin φ approaches 0, appreciable deformations must occur in all cases if destructive cohesive stresses are to be avoided.

4. Relationship to Fundamental Film Properties

To utilize the foregoing findings, it is necessary to develop the quantitative relations between sin φ or blister deformation, and the physical properties of real films. From the half-angle formula

$$\sin \varphi = 2 \sin \frac{\varphi}{2} \cos \frac{\varphi}{2}$$

it may be demonstrated that

$$\sin \varphi = \frac{2\,hr}{h^2 + r^2}\,. \tag{3}$$

The area deformation of the film is

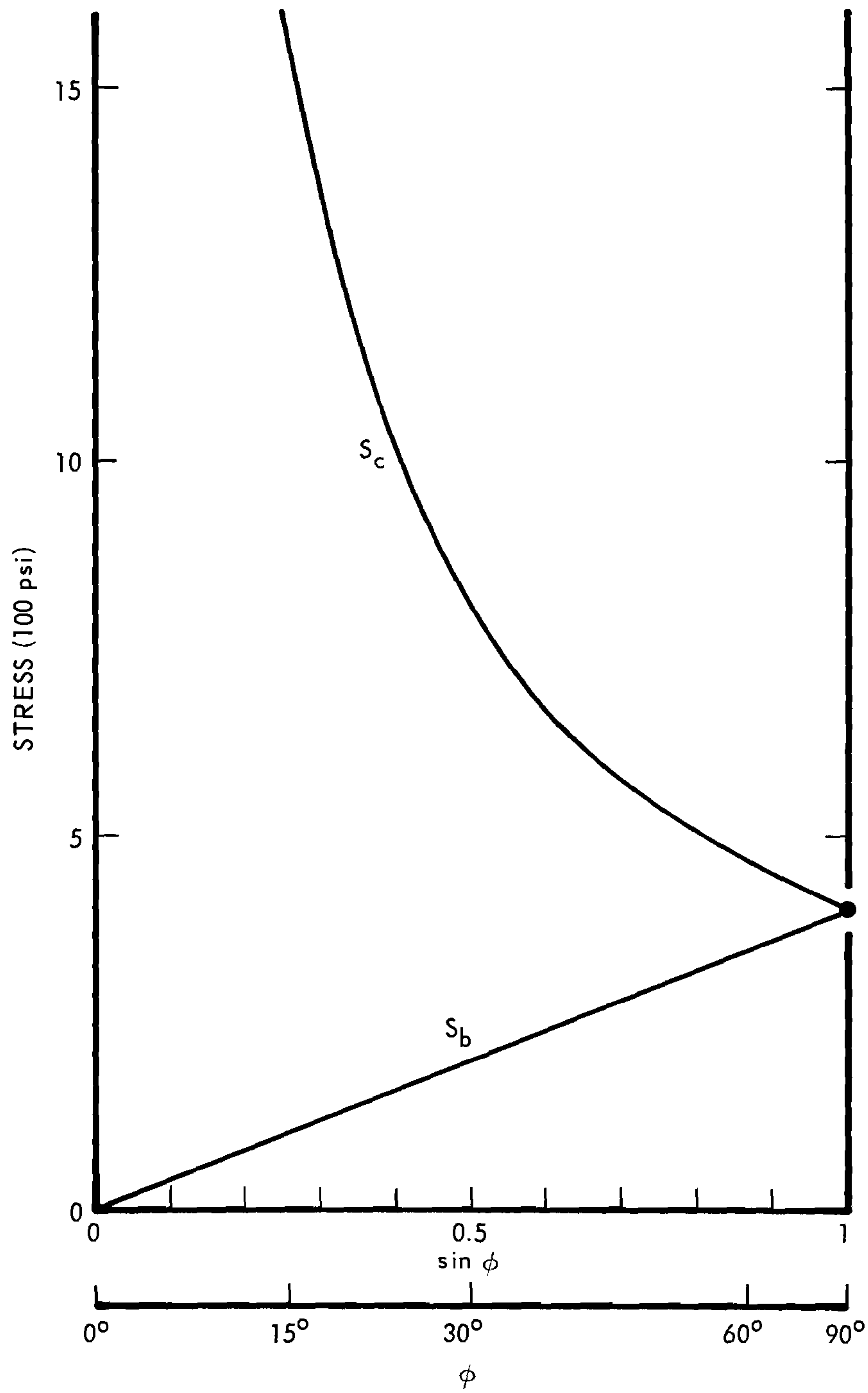

Figure 8. Bond and Cohesive Stresses as a Function of Sin ϕ (Deformation).

$$e = \frac{\Delta A}{A_{cir}} = \frac{A_{sph} - A_{cir}}{A_{cir}} = \frac{A_{sph}}{A_{cir}} - 1 \tag{4}$$

$$= \frac{2\pi hr/\sin\varphi}{\pi r^2} - 1 \quad \text{[From area substitutions]}$$

$$= \frac{\cancel{2}\cancel{\pi}(h^2 + r^2)}{\cancel{2}r^2\cancel{\pi}} - 1 \quad \text{[From (3)]}$$

$$= \frac{h^2}{r^2}. \tag{4a}$$

By definition the tensile modulus,

$$E = \frac{s_c}{e_t}, \tag{5}$$

where:

e_t = uniaxial tensile elongation.

But, at the periphery of the blister, lateral elongation is restrained, therefore the uniaxial elongation is quantitatively almost exactly equal to the area elongation, or

$$e_t = e \qquad \text{and}$$

$$E = \frac{s_c}{e}. \tag{6}$$

By substituting Eq. 3 in Eq. 1, eliminating h with Eq. 4a, and e with Eq. 6, it may be demonstrated that

$$P = \frac{4ts_c^{3/2}E^{1/2}}{r(s_c + E)}. \tag{7}$$

In a similar manner, by substituting Eqs. 3, 4, and 6 in Eq. 2 one obtains

$$P = \frac{ts_b(s_c + E)}{rs_c}. \tag{8}$$

The values of P given in Eqs. 7 and 8 are now equated to yield

$$s_b = \frac{4s_c^{5/2}E^{1/2}}{(s_c + E)^2} . \tag{9}$$

Eq. 7 expresses pressure in terms of the blister geometry, tensile stress, and modulus; Eq. 9 demonstrates that the required bonding stress is dependent only on tensile stress and modulus. These facts can be seen more clearly by plots of the relationships of Eq. 7 and 8 on selected coordinates. For this purpose we rearrange Eq. 7 as

$$s_c = \frac{Pr}{4t} \frac{(\frac{s_c}{E} + 1)}{(\frac{s_c}{E})^{1/2}} \tag{10}$$

and Eq. 8 as

$$s_b = \frac{\frac{Pr}{t}}{1 + \frac{E}{s_c}} . \tag{11}$$

Graphical solutions of Eqs. 10 and 11 are presented in Figures 9 and 10, respectively. These two graphs provide all theoretical criteria for static equilibrium of a peripherally bonded spherical shell segment.

5. Theory of Blister Formation

In the preceding discussion, the force equilibrium equations were developed in terms of linear or uniaxial stress and tensile modulus. It will have become obvious at the same time that blister configuration can provide a means of measuring film stress-strain characteristics. For this purpose, we may equate the air pressure-volume work under the blister with the film deformation work:

$$P\Delta V = t\bar{s}_o\Delta A , \tag{12}$$

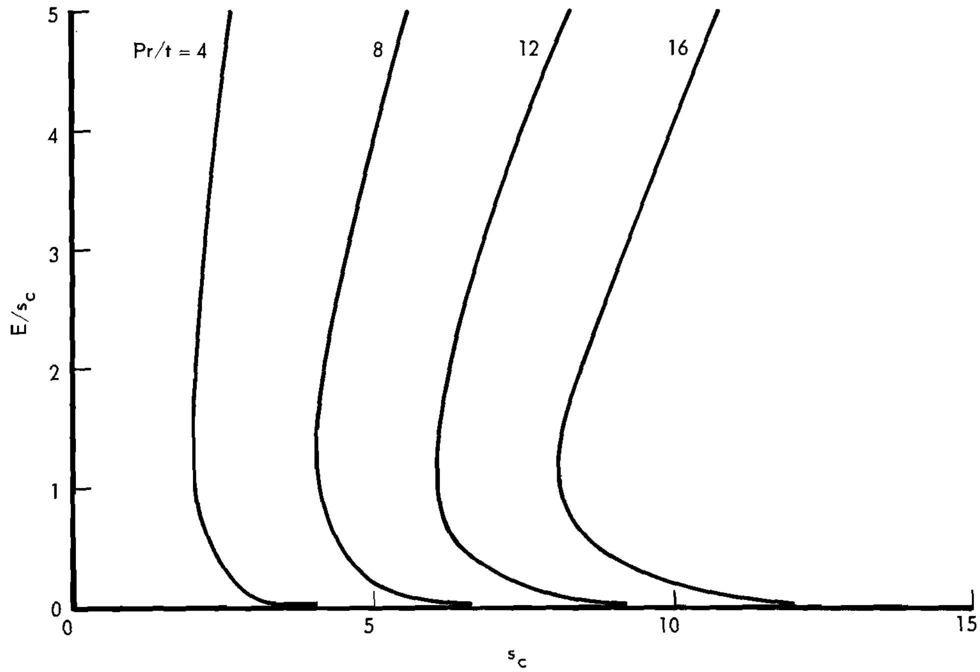

Figure 9. Graphical Solution of Equation 10.

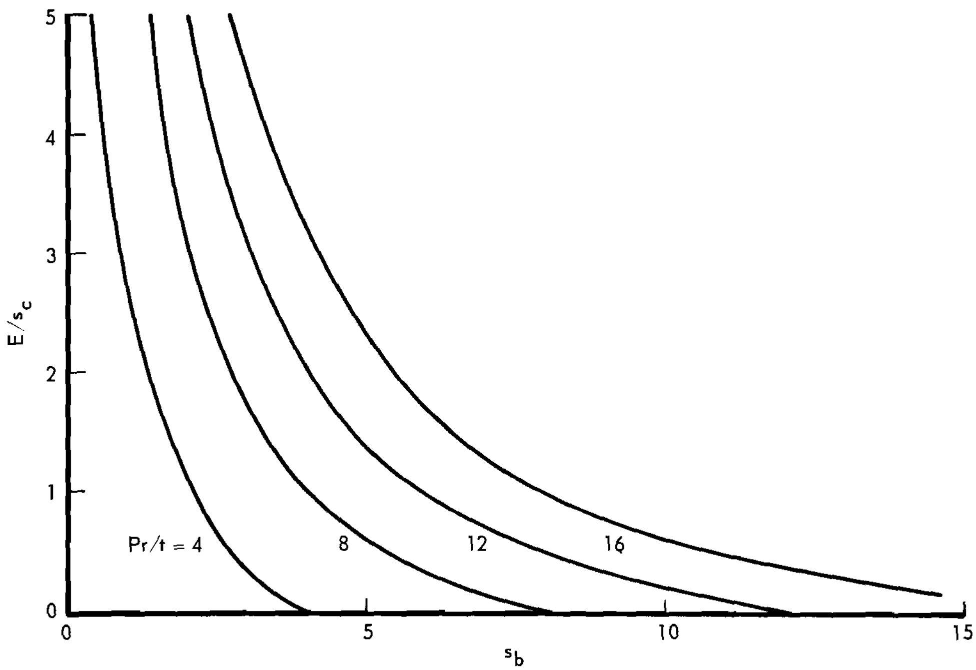

Figure 10. Graphical Solution of Equation 11.

where:

P = pressure under film

V = ΔV = volume within blister

t = film thickness

$\bar{s}_o$ = average combined stresses in unit area of film

A = initial flat circular film area.

Since (Eq. 4) $e = \Delta A/A$, substitution in Eq. 12 provides

$$P = \frac{At\bar{s}_o e}{\Delta V} . \qquad (13)$$

The geometrical formulas,

$$A = \pi r^2$$

and

$$V = \frac{1}{6} \pi h(h^2 + 3r^2)$$

are then substituted in Eq. 15, yielding for the pressure

$$P = \frac{6tr^2\bar{s}_o e}{h(h^2 + 3r^2)} . \qquad (14)$$

Within the elastic limits of the film

$$s_o = 2\bar{s}_o ,$$

where:

s_o = final combined stress in unit area of the film.

Substituting s_o in Eq. 14 and eliminating h with Eq. 4a,

$$P = \frac{3ts_o e^{1/2}}{r(e + 3)} . \qquad (15)$$

Eq. 4 defined e as the area elongation and, since this analysis is not confined to the blister periphery, it is appropriate to define an area tensile modulus as

$$E_o = \frac{s_o}{e} . \tag{16}$$

Thus

$$P = \frac{3t\left(\frac{s_o}{E_o}\right)^{1/2} s_o}{r\left(\frac{s_o}{E_o} + 3\right)} = \frac{3ts_o^{3/2}E_o^{1/2}}{r(s_o + 3E_o)} . \tag{17}$$

The similarity to Eq. 7 is striking. The equations are not identical as

$$s_o \neq s_c$$

and

$$E_o \neq E.$$

However,

$$e = e$$

and

$$P = P.$$

Therefore, from Eqs. 6, 7, and 15,

$$s_o = \frac{4s_c(e + 3)}{3(e + 1)}. \tag{18}$$

At slight deformations, where $e \rightarrow 0$,

$$s_o \cong 4s_c, \tag{19}$$

while at larger deformation, such as one of $\varphi = 90^\circ$, then $e = 1$, and

$$s_o = \frac{16}{6} s_c = 2.67 \, s_c . \tag{20}$$

The area combined stress s_o is computable from blister pressure P and area deformation e by Eq. 15; it follows, therefore, that suitable experiments might be performed on paint film blisters to determine stress-strain characteristics in terms of s_o and e. The results could then be applied to the previously developed static equilibrium criteria by utilizing Eq. 18 to solve for corresponding values of s_c. Also, such blister experiments might be used with films of known s_c and E properties to test the validity of the theoretical criteria.

Useful application of the foregoing theoretical development rests on the premise that uniform (fluid) pressures are the primary cause of those film failures that are ultimately observed as chipping or flaking.

6. Relationship to Performance

For a given coating-substrate system a yield pressure value P_y is computed from experimentally determined values of bond yield stress s_{by}, tensile yield stress s_{cy}, and modulus E, in accordance with Eqs. 10 and 11. The solution may be conveniently expressed in terms of $(\frac{Pr}{t})_y$, the "stress resistance factor" which is itself independent of blister radius and thickness. The stress resistance factor $(\frac{Pr}{t})_y$ characterizes the inherent capability of a film to resist removal from a given substrate under the influence of normal pressures.

It will now be necessary to develop the laboratory or field performance test situation in analytical terms to clarify the relevance of the stress resistance factor. Performance observations, Q, are normally recorded and plotted as a function of time θ. Values of Q are related to an arbitrary scale ranging from 1 to 10. For example we may plot chipping (ASTM-D-913-51) against time in days on the highway; the effective life of the coating may be characterized by the time, θ_5, required for the coating to reach condition

5. A further characterization, $\Delta(\theta_{7-3})$, indicates the rate of change of Q in the range of interest between conditions 7 and 3. A plot of these relationships is shown in Figure 11. If the realistic assumption is made that values above 7 and those below 3 may be neglected as irrelevant, then these two parameters are completely adequate to define performance.

It is now desirable to relate these performance characteristics to the fundamental film properties. For this purpose performance curves are defined in polynomial form,

$$Q = a - b\theta - c\theta^2 - d\theta^3, \tag{21}$$

where:

a, b, c, and d are coefficients describing the placement and shape of the curve*.

If experimental data cannot be fitted to this polynomial, it suggests the occurrence of catastrophic phenomena which are discontinuous in time. Furthermore, the parameters θ_5 and $\Delta(\theta_{7-3})$ can be derived as functions of a, b, c, and d.

The general relation of rate theory is

$$\frac{dQ}{d\theta} = \frac{\Delta F}{R}, \tag{22}$$

where:

Q = the quantity undergoing change

θ = the time

ΔF = the driving force

R = the resistance.

*See Burrows, W. H., "Graphical Techniques for Engineering Computations," New York, Chemical Publishing Company, 1965; pp. 198 ff.

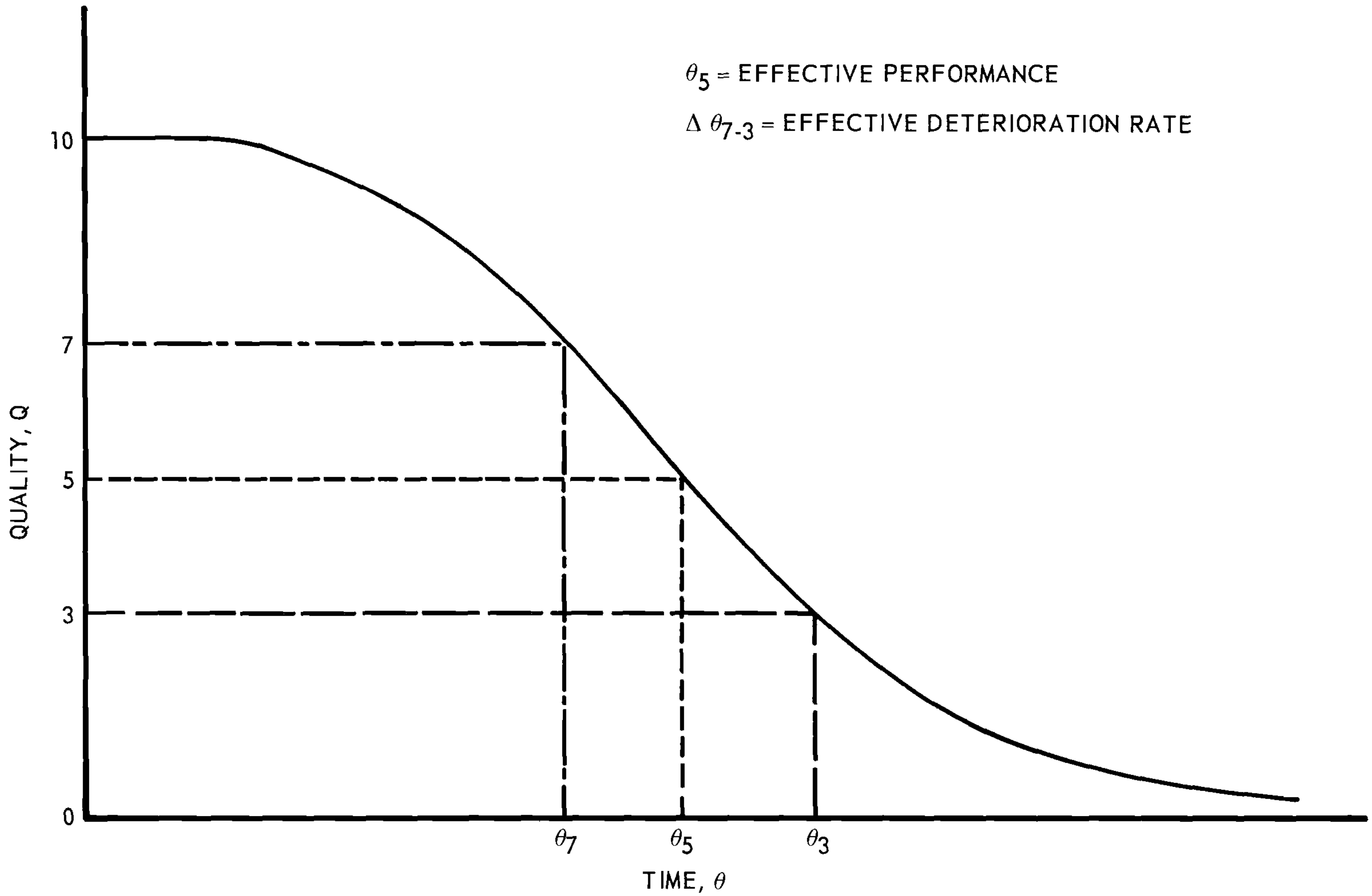

Figure 11. Film Quality versus Time of Weathering.

In any application of this relationship, the most crucial problem is to determine the appropriate driving force and resistance for the rate process in question. The technique of dimensional analysis may be employed, intuitive judgment is valuable, and experimental verifications are essential.

As an example of the intuitive approach to the highway chipping phenomena, we may write

$$\Delta F = K' \, \overline{N} \, \overline{W} \, \overline{V}, \tag{23}$$

where:

K' = proportionality constant

$\overline{N}$ = average frequency of tire impacts

$\overline{W}$ = average tire inflation pressure

$\overline{V}$ = average vehicle velocity,

and that

$$R = K'' \left[\Sigma \frac{(\frac{Pr}{t})_{y\theta} \cdot t_\theta}{A_\theta r_\theta} \right] A \, , \tag{24}$$

where:

K'' = proportionality constant

A = total area over which summations are taken and subscripts θ refer to small homogeneous "blister systems" at time θ .

Should these blister systems be classified by substrate type (mortar matrix and aggregate surface) and by size distribution, the summation would involve two separate sets of the parameters. However, a simplification may be made by simply considering <u>average</u> parameters, thus,

$$R = K'' \left(\frac{\overline{Pr}}{t}\right)_{y\theta} \cdot \frac{\overline{t}_\theta}{\overline{r}_\theta} . \tag{25}$$

Let:

$$\frac{K'}{K''} = K. \tag{26}$$

Substituting 3, 5, and 6 in 2, we obtain

$$Q = K \int_{0}^{\theta_Q} \frac{\bar{N}\,\bar{W}_\theta \bar{V}_\theta}{\left(\frac{\bar{P}r}{\bar{t}}\right)_{y\theta} \frac{\bar{t}_\theta}{\bar{r}_\theta}} \cdot d\theta .$$

For any given experiment, $\bar{N}$, $\bar{W}$, and $\bar{V}$ may be regarded as invariant with time and may be removed from the integral. The resulting value of Q may be equated with that given in Eq. 21; whence,

$$Q = K\bar{N}\bar{W}_\theta \bar{V}_\theta \int_{0}^{\theta_Q} \frac{d\theta}{\left(\frac{\bar{P}r}{\bar{t}}\right)_{y\theta} \frac{\bar{t}_\theta}{\bar{r}_\theta}} = a - b\theta - c\theta^2 - d\theta^3. \tag{27}$$

If the driving force and resistance are properly selected, and if each variable can be expressed as a function of time θ, then, utilizing polynomial coefficients derived from highway data, we can solve the equations for K at various times (θ_s). If K has a constant value of 1 at any θ, our theory correlates perfectly with observation, and performance of any system would be predictable if its individual variables could be expressed as functions of time. If K has a constant value other than 1, but is invariant with time, then only some constant factor is missing (or superfluous) in our rate equation. If the same K value is obtained with different coatings, then the missing (or superfluous) constant is in the ΔF part of the equation; if different with different coating, but still invariant with time, the missing (or superfluous) constant is in the resistance, R. By a similar logical process if K varies with time, the source of variance can be located in $\triangle F$ or R by observing whether or not it is affected differently by different coatings (coatings should affect only R). Thus by a trial and error process one may perfect the parametric relationships of the rate equation and the techniques for measuring or estimating the variables collectively or individually as a function of highway time.

Presumably, if a means were found to condense highway time (simultaneously accelerate all variables at proportional rates) then a laboratory experiment performed in condensed time could be expanded to real time to predict performance. This was essentially our initial experimental approach on this project as it has been with others experimenting in this area. That it was not completely successful is an indication that proportional overall acceleration of all variables in a single experiment is virtually impossible to achieve. It is apparent, therefore, that the rational approach to prediction is to determine how the individual quantities $(\frac{\overline{Pr}}{t})_y$, $\overline{t}$, and $\overline{r}$ vary with highway time, and subsequently with accelerated environmental simulations which would be related to highway time.

Most of the theoretical approach outlined here has been developed in the course of writing this report. The development has now proceeded to the point that we can now anticipate realistically a means of relating the parameters $(\frac{\overline{Pr}}{t})_y$, $\overline{r}$, and $\overline{t}$ to time θ in such manner that accelerated test results can be translated into highway service life expectancies. There is much work still to be done - completion of the theoretical approach for each individual parameter, development and standardization of test procedures, and correlation studies. But we are confident that it can be done.

We would conclude this purely theoretical discussion by venturing the opinion that regardless of the degree of sophistication attempted in predicting performance by the methods outlined; the parameter $(\frac{\overline{P}r}{t})_y$ by itself should be most helpful to the paint formulator as a measure of the primary characteristics of a paint film which enable it to resist physical destruction.

C. Interpretation of Test Data

The foregoing theoretical developments impart new perspectives to both the design and interpretation of experimentation; however, since the experimental work of this program preceded the theory, the latter is applicable in this project only to interpretation of existing test data.

1. Accelerated Wear Tests

The indicated ability of the accelerated chipping-adhesion test performed on the accelerated wear tester to correlate with highway test results is all the more remarkable in the light of theoretical considerations. The driving forces in the accelerated test are clearly different from those on the highway, since shear is a large factor in the laboratory test. Possibly the added shear compensates for the lower velocities on the tester. On the other hand, the added shear tends to promote premature destruction of films which may be somewhat soft initially. Clearly, the driving forces in the accelerated test are applied to the film during a time that the maximum film resistance properties are developing, and the test is probably completed before these properties, $(\frac{\overline{P}r}{E})_y$, have begun to deteriorate appreciably. If this be true, the implication is that good highway paints subjected to heavy traffic loads are similarly destroyed mechanically before other environmental factors are significantly manifested. Thus it might only be necessary to measure $(\frac{\overline{P}r}{t})_y$ at an appropriate stage of cure, to assess the paint's durability potential, or even to predict its performance.

The accelerated chipping-adhesion tests performed on a variety of special substrates were of special theoretical interest because they clearly indicated that adhesive strengths are the present limiting factor in paint performance, even though the theory requires that cohesive strengths be higher. Probably the exaggerated shearing stresses in the test increase the adhesive strength requirements as compared with the highway, but improved adhesion is undoubtedly the key need in either case.

The abrasion tests on the accelerated wear tester are probably of greater potential rather than immediate value. These tests may adequately represent the relative rates of loss of film thickness. These data would be needed in the overall rate equation even though failure is by chipping-adhesion.

2. Physical Characterization Tests

The limitation of the physical characterization tests become painfully evident when a performance theory has been developed in terms of basic properties. These "hybrid" tests neither simulate field performance nor measure basic properties. On the other hand they do permit some inferences about both. We may be reasonably certain that our test paints exhibit somewhat different initial properties and that these properties change differently during a brief ageing period. Thus the appropriate time to measure the $(\frac{\overline{Pr}}{t})_y$ property of a paint may be very critical if a reliable assessment of its performance potential is to be obtained.

It is feasible to attempt a ranking of basic properties of the several paints based on the "hybrid" tests. Such rankings are shown in Table X based on the aged condition of the films. Bond stress, s_{by},

TABLE X

PHYSICAL PROPERTIES RANKED FROM "HYBRID" TESTS

Paint	Physical Property Rankings			
	s_{by}	s_{cy}	E	$(\frac{\overline{Pr}}{t})_y$
90 Std. Alkyd	3	2	2	3
84 Chlor. Rub.-Alkyd	2	4	3	2
88 Epoxy Ester	1	3	4	1
86 B/VT Resin	4	1	1	4

rankings are based on the Adherence Number and Reverse Impact data. Cohesive stress, s_{cy}, is derived from the pencil hardness values, although it is apparently not a limiting factor in performance anyway. Modulus is inferred from the Pencil Hardness and Mandrel Tests. It will be seen that the $(\frac{\overline{Pr}}{t})_y$ value of the Epoxy Ester (#88) would be the highest, followed in order by #84, #90, and with #86 a distinct last place. These hybrid tests can, at least, be said to be compatible both with our theory and with our field experience.

VIII. CONCLUSIONS

An accelerated wear testing machine and operating procedures have been developed to yield performance correlations* with concurrent highway cross-stripe tests conducted on Interstate 85 in Atlanta, Georgia. These performance correlations are not, in general, attainable from a single set of operating conditions; rather, they require testing under at least

*Performance correlation in this context is intended only to connote an ability to rank paints in the laboratory test in the same order of performance as observed on the highway.

two sets of conditions to evaluate individually the susceptibility of traffic paints to both erosive and chipping modes of failure. While, in the present study, correlation was obtained by characterizing a given paint entirely by its poorest attribute (chipping), it is doubtful that this particular procedure has general applicability; indeed, it is more probable that specific correlations should be derived separately for individual highway conditions. Such derivation was beyond the scope of the present project, but the dual test procedure has contributed a substantial advantage in making possible a generalized approach. In fact, the accelerated wear tests may without further modification adequately correlate highway performance under a wide range of conditions by properly weighting the performance factors of erosion and chipping.

Conclusions as to the applicability of the accelerated wear testing procedures for various needs are summarized as follows:

A. Significance for Acceptance Testing

Hickson's original testing machine was utilized in Federal Specification TT-P-115 for acceptance testing of traffic paints for many years. The procedure involved comparative testing of sample paints against a standard control paint under one set of operating conditions. In the light of present knowledge, it is recognized that this procedure evaluated primarily the relative erosion-abrasion resistance of traffic paints, and for that purpose it was entirely valid. In other words the test evaluated a necessary performance attribute, but was not of itself entirely sufficient to assure fully adequate field performance. By utilizing the equipment and procedures described in this report, a more adequate performance evaluation can be obtained. A difficulty in this testing is that painstaking panel preparation and coating procedures are involved and replications are essential for reliable interpretation. Such expensive and time consuming procedures are not generally appropriate for batch testing. The investigators conclude that the accelerated wear test procedures are suitable as a means of accepting or rejecting candidate paint formulations for use by highway departments, providing the components of the formulation are known so that effective chemical and physical test methods can be utilized for batch acceptance tests. Regardless of the validity of accelerated wear tests, the abandonment of physical and chemical batch testing cannot be justified. These analytical tests provide a necessary precision of quality control that is inherently unattainable in ultimate performance testing.

B. Significance for Specification Development

The argument in some quarters that specifications are always 10 years behind the times is not totally refutable. At the same time, difficulties in characterization and evaluation have dictated a conservative attitude toward novel developments. The new information developed in the present program can reduce some of the lag in specifications development by an improvement in the reliability and speed of performance evaluations. Arguments regarding performance versus compositional type specification would be resolved by the judgment that both elements should be embodied in a manner that avoids mutually-exclusive requirements and encourages the ingenuity of vendors, but assures reliable and economical maintenance of quality.

C. Significance for Applied Research

It is characteristic of research that it usually uncovers more questions than it answers. This project has developed equipment and methods useful for traffic paint research, but it has also disclosed needs for further knowledge and refinements of methods.

Many of these needs center around the subject of paint adhesion and paint-substrate-traffic interactions. Means of characterizing highway substrates for "adherability" are needed. Future decisions must be made that traffic paint shall be designed either for optimum performance on the poorer substrates or, alternatively, that substrates must be modified by cleaning and/or priming to achieve the stability necessary for superior paint performance. The findings of this investigation suggest that the former approach may already be exploited to about its maximum potential. Increasing attention to substrate modification is indicated.

Despite some digressions (which were, nevertheless, within the proposed scope), this project has been oriented rather narrowly toward the objective of accelerated laboratory performance test development. Once started, it could never be completed in an absolute sense. Infinite variations are possible, and some real needs remain to be fulfilled. The most significant present need is for improvement in the reliability of testing for the chipping mode of paint failure. One can argue on theoretical grounds that poor precision is characteristic of discontinuous failure phenomena, but substantial improvement may still be feasible.

A very important capability of accelerated wear testing as presently developed is that it provides standardized performance conditions and results against which the contributions of individual properties of a traffic paint film to its performance may be evaluated. In view of the preliminary efforts in this direction reported herein (Section VI and VII), definite optimism for the potentials of this approach is fully justified. Traffic paint formulation can never attain engineering dignity until rational design is based upon materials properties. The application of design principles rather than Edisonian type research should characterize future programs of formulation development in this field.

D. Significance for Basic Research

The theoretical study of Section VII provides an advanced point of departure for needed basic research. This basic research would not be of the so-called "ivory tower" type, having no relation to applications; rather, it would have as its goal the development of a sound working theory of paint performance. It is only from such a working theory that one can hope to achieve the aforementioned rational paint design based upon materials properties. Much of the data developed in the present program can be applied to theoretical development; and the accelerated wear tester can provide a means of testing theoretical models in addition to serving as an accelerating device for observing individual and collective physical property changes in "condensed time."

IX. APPENDIXES

A. Concrete Disc Preparation

B. Test Specimen Preparation

C. Special Night Visibility Meter

D. Accelerated Wear Test Data

E. Film Characterization Test Methods

F. References Cited

A. Concrete Disc Preparation

A. Molds

A set of 20 special molds were constructed for casting concrete discs. Each mold consisted of a round plywood base, a removable steel side strip, and a central vertical mandrel over which 1" diameter x 1.5" lengths of aluminum tubing could be placed to provide a reinforced central hole in the discs. A photograph of the assembly is shown in Figure 12.

B. Concrete Mix Design

Initial efforts to utilize gravel in sizes of 1/2" yielded mixes which were difficult to place in the molds. Further experimentation indicated that a relatively "rich" mix utilizing 1/4" stone was required for satisfactory placement. The selected mix had the following composition:

cement	-	25 lbs.
concrete sand	-	46 lbs.
1/4" stone	-	69 lbs.
Water	-	14 lbs.

C. Mixing, Placement and Curing

Mixes were prepared in a mechanical batch mixer. Concrete was delivered directly from the mixer into the molds. The filled molds were vibrated, trowelled, and covered with wet burlap to set up overnight. The following day the concrete discs were stripped from the molds and damp-cured for 30 days at 70° F.

D. Disc Grinding

To produce true and uniform "worn" concrete surface on which to apply paint, the discs were faced on the "stonemill" device shown in Figure 13. Two concrete discs, serving as grindstones, faced each other.

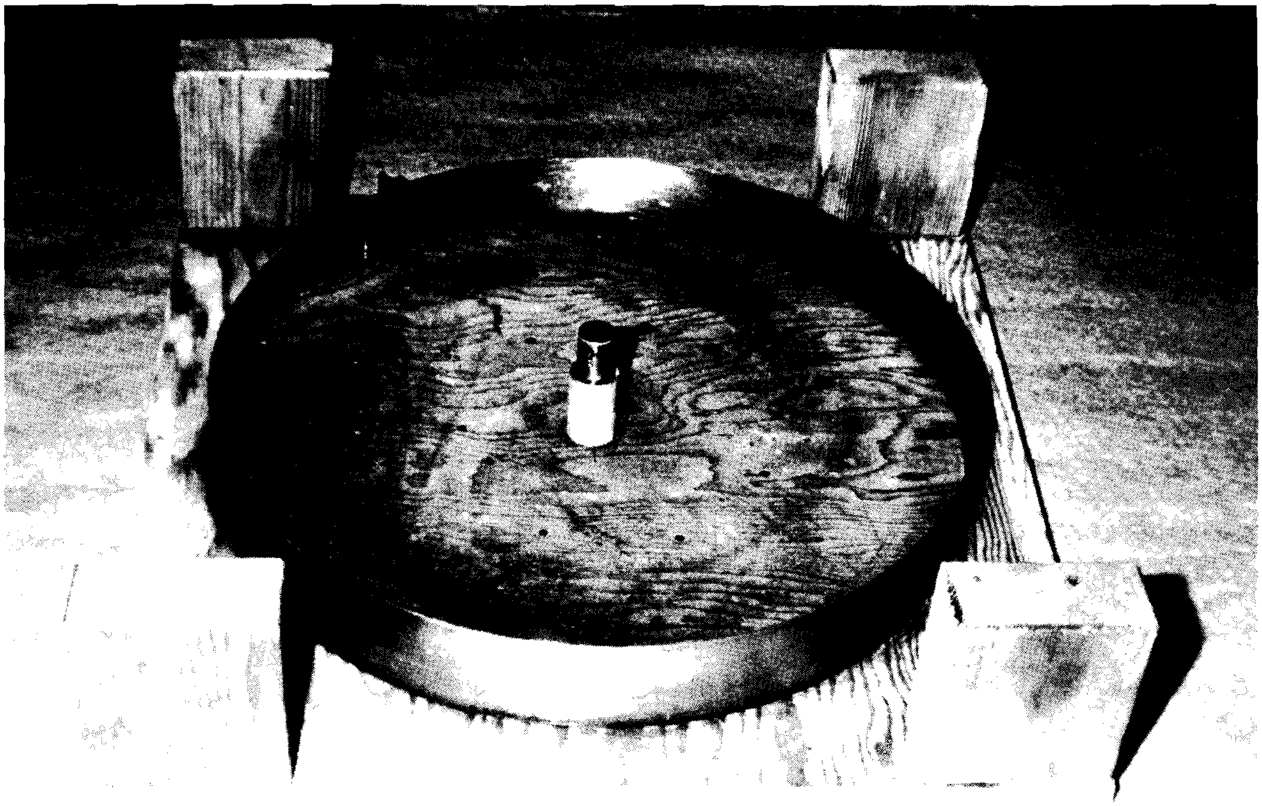

Figure 12. Disc Mold.

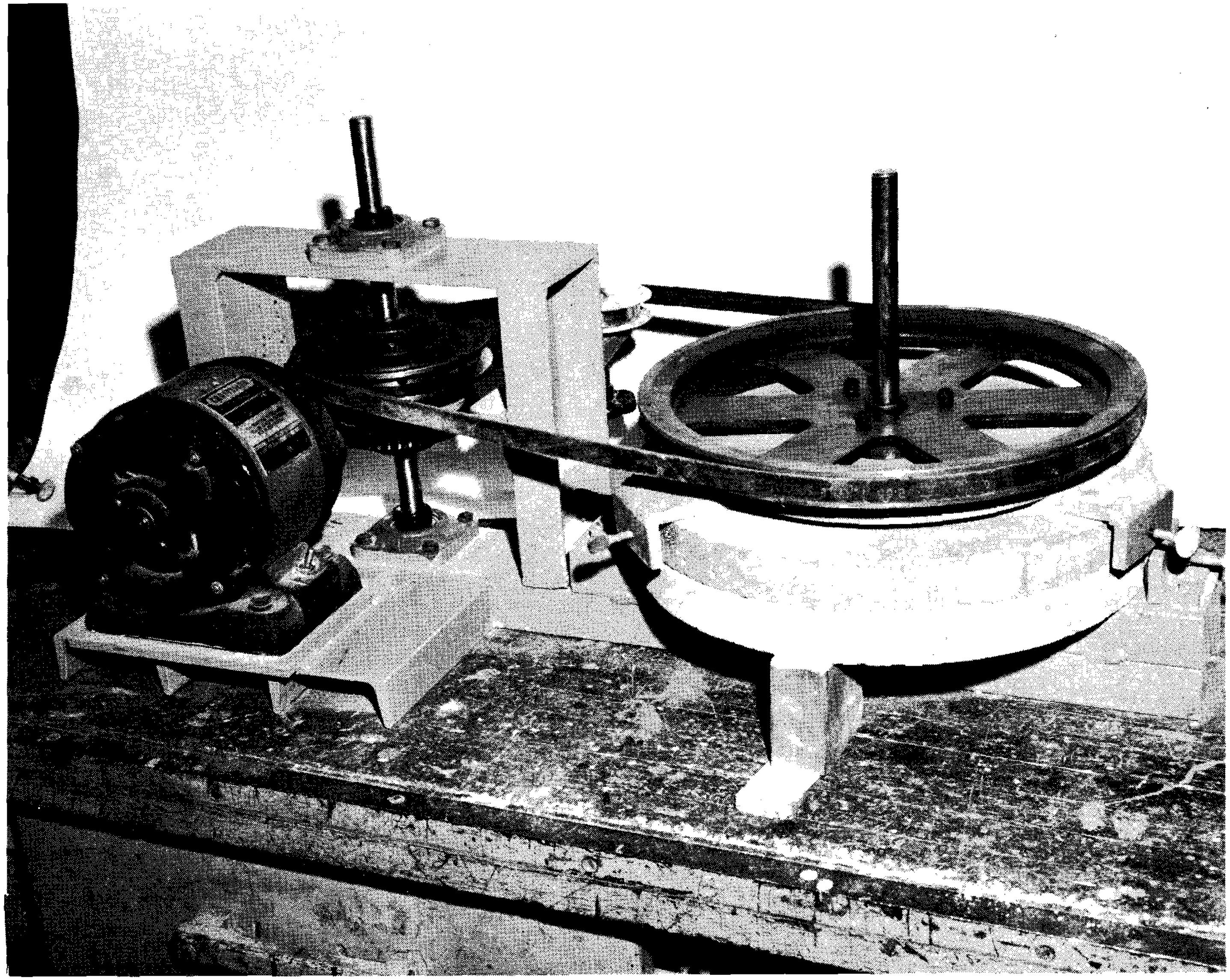

Figure 13. Disc Facing Machine.

Sand was placed between the lower stationary and the upper rotating disc, and the sand was wetted occasionally by pouring a small amount of water over it. This grinding procedure yielded surfaces of satisfactory trueness and uniformity. The appearance of the finished discs is shown in Figure 14. Note the trueness achieved in the aggregate-studded surface, as indicated by the continuous contact of the straight edge ruler.

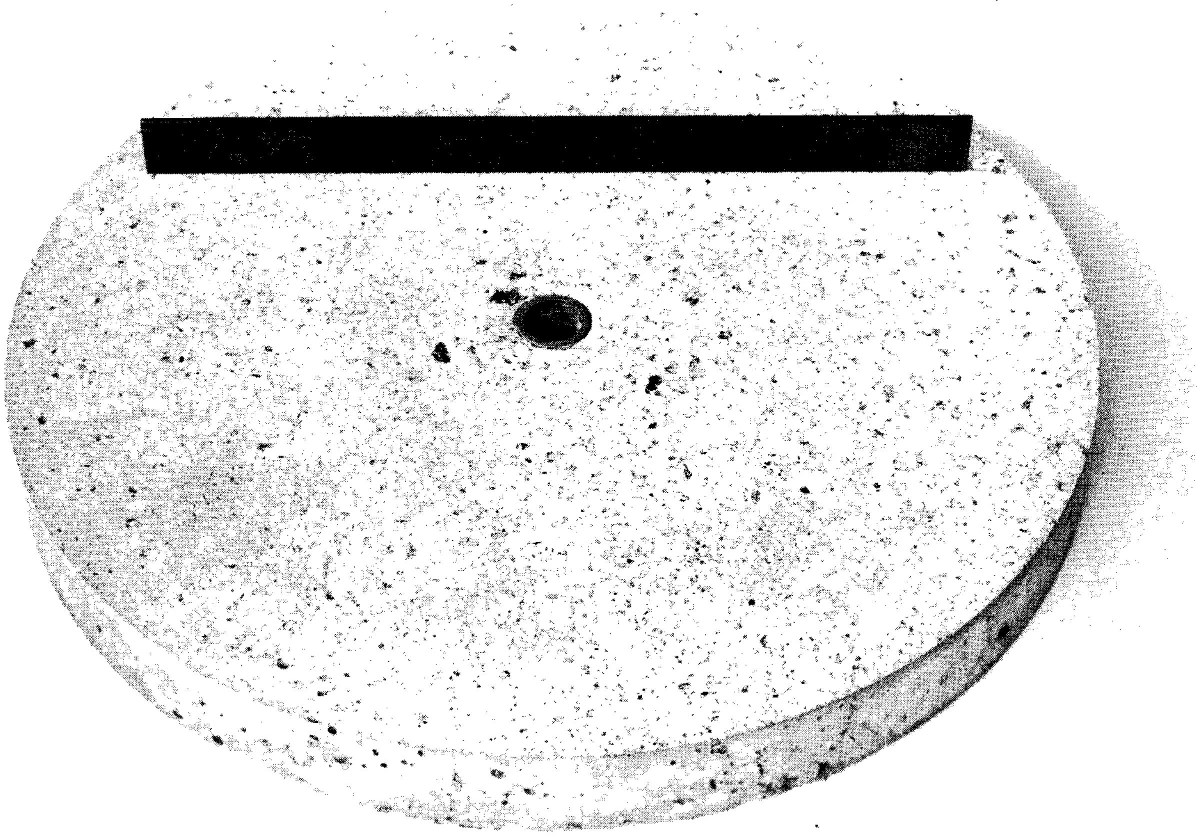

Figure 14. Faced Disc.

B. Test Specimen Preparation

A. Paint Application

Faced concrete discs were patterned to accommodate six radially oriented uniformly spaced paint test stripes. The symmetrical pattern was established by applying narrow strips of cellophane tape to the bare concrete to form radial "centerlines" for each four inch width of test stripe. The tape "centerlines" served two purposes: (1) to divide the paint stripes in halves - the left half received beading; the right half was left unbeaded - and (2) to provide an unpainted "datum elevation" at the center of each stripe to enhance the precision of film thickness determinations.

Paint was applied by a "draw-down" technique. Shim templates of appropriate thickness were positioned on either side of the tape "centerlines" to outline a 4 inch radial stripe. A 3/4" diameter doctor rod was positioned across the shims toward the disc center. A quantity of paint was puddled immediately in front of the rod, and the rod was drawn forward smoothly toward the disc periphery to cast a uniform paint stripe between the templates. The paint dries rapidly, and within a few minutes time the templates and the cellophane strip can be removed to leave a uniform 4 inch paint stripe with a narrow unpainted band at the center.

B. Laboratory Bead Applicator and Technique

Preliminary experiments had indicated that beading uniformity was a critical variable in both laboratory and field work. A simple bead distributor device was constructed for beading of laboratory specimens, as illustrated in Figure 15.

Hardware cloth of about 10 mesh was inserted at right angles in a 24 inch length of 5 inch diameter vent pipe at 3 different levels. The end of the tube was provided with a circular plate having a $3\frac{1}{2}$" x 3" open

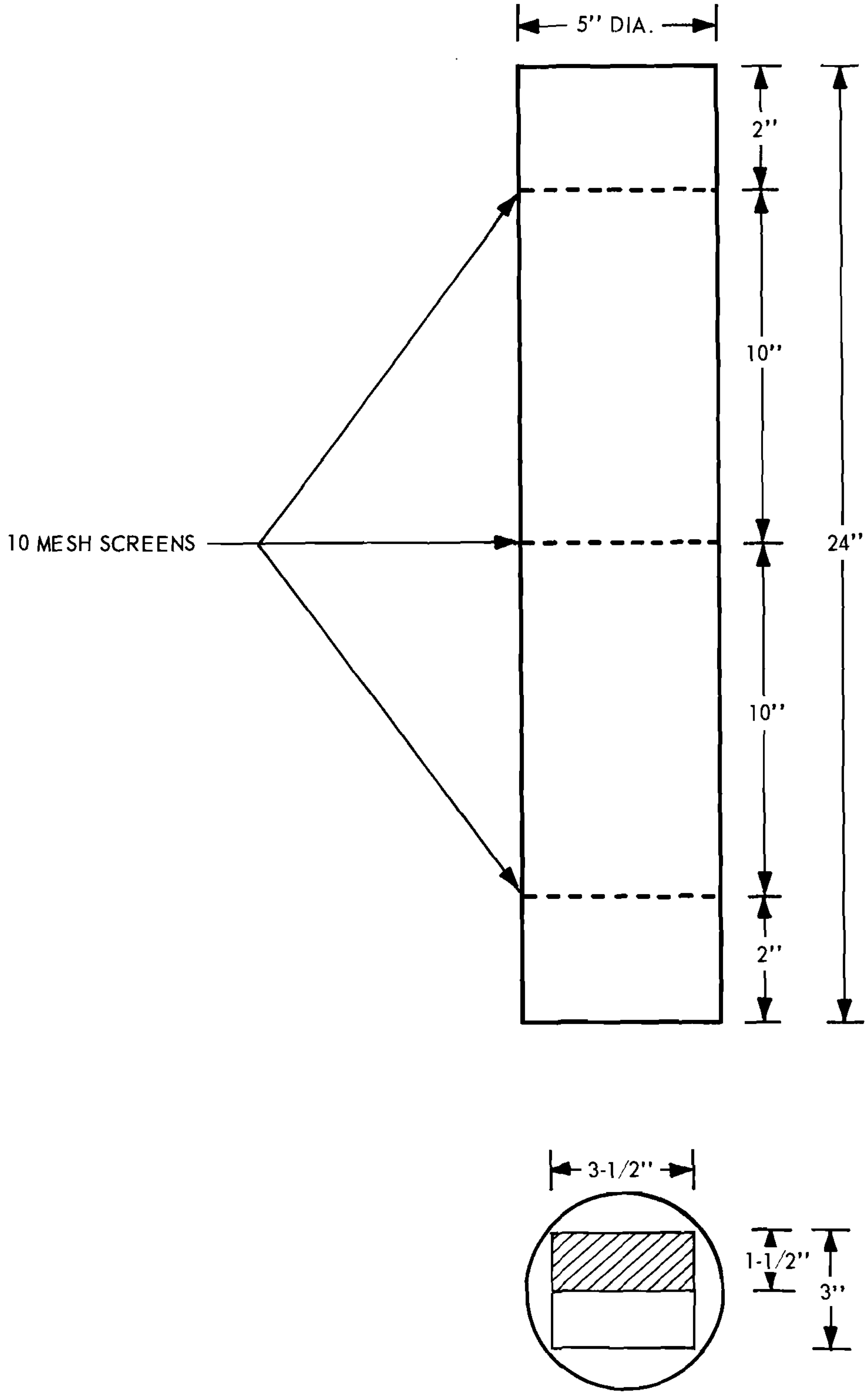

Figure 15. Laboratory Bead Applicator.

window. Beads dropped from the top of the tube reached a fairly even distribution by the time they reached the bottom. Any beads falling outside of the window were retained on the plate, which was covered with foam rubber to keep the excess beads from bouncing off and falling through the window. Another piece of sheet metal $1\frac{1}{2}$" x $3\frac{1}{2}$" was formed for insertion on the open window in such a way that beading could be confined to one-half of the painted area.

With the right half of the window covered (our usual laboratory procedure for testing paints) 26% of the beads introduced on the top of the tube were distributed uniformly over the left $1\frac{1}{2}$" x $3\frac{1}{2}$" area. The amount of beading, or bead density, could be closely controlled by weighing the proper amount of beads to introduce at the top of the tube.

Beading was applied to test specimens immediately following paint application and while the paint was in its initial wet state. The beader was quickly positioned over the wet specimen, and a standard quantity (3.6 g) of beads were introduced at the top of the beader. The quantity delivered through the window (0.94 g) was equivalent to 6 pounds per gallon of paint as the paint is applied on the highway in a 4" stripe at 15 mils wet thickness.

C. Film Thickness Measurement

Dry film thicknesses of paint test specimens were measured with a dial indicator, reading to .001 inch, attached to a brass "bridge" as shown in Figure 16. The bridge was placed over the paint stripe and a thickness profile was established from multiple readings on the paint, on the bare surface on either side, and at the "centerline."

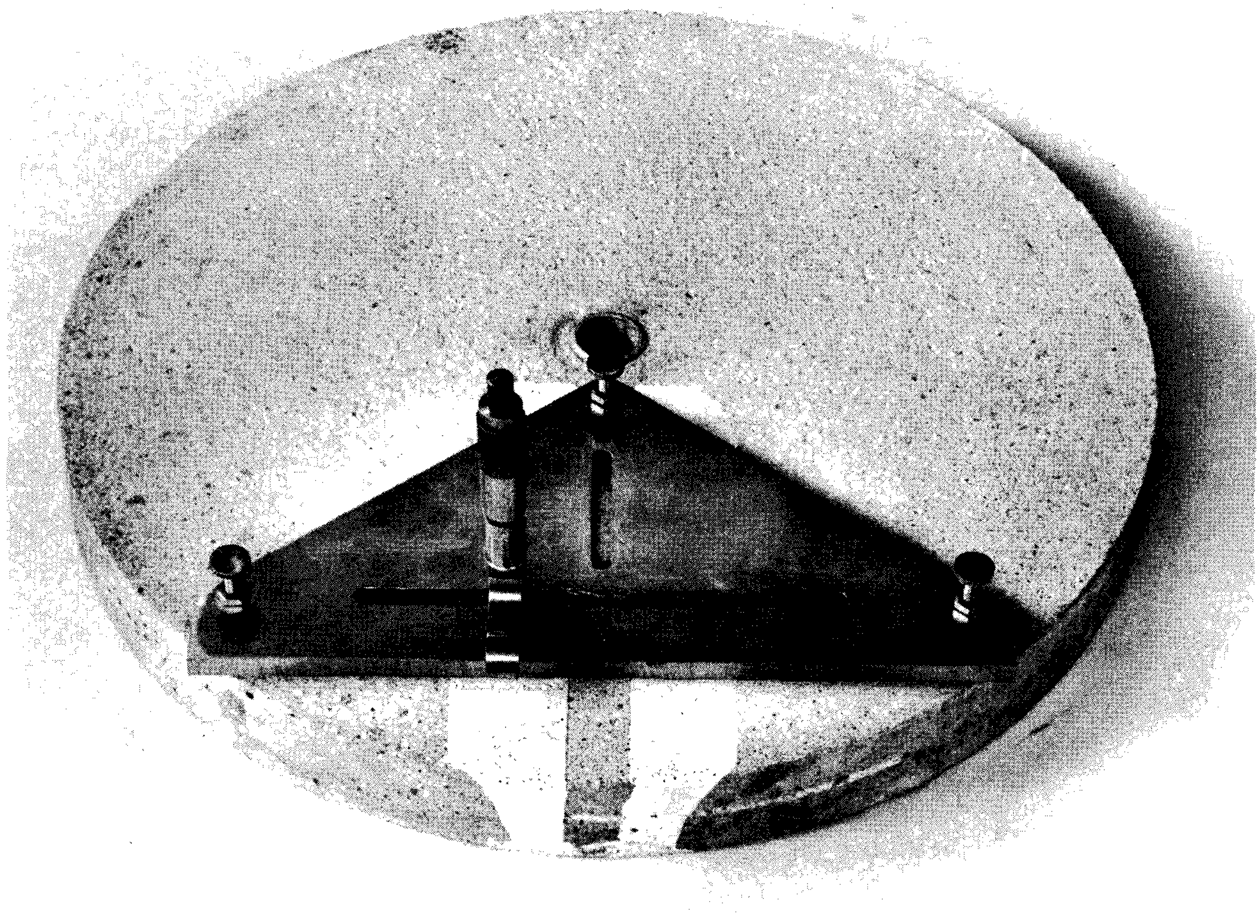

Figure 16. Film Thickness Measurement "Bridge".

C. Special Night Visibility Meter

A. Purpose and Design Considerations

The size restrictions imposed by the one inch line width and two inch tread on the laboratory wear tester limit the size of the inspection area to approximately a 1 x 2 inch rectangle. This area of highway paint was too small for standard measurements and led to the design of the Special Night Visibility Meter for laboratory use. While a very low angle of incidence is consistent with actual road conditions, it is difficult to maintain a low angle with necessary precision in a small, simple instrument. The size limitations dictated that the retroreflectance should be measured at a "practical" angle of incidence. A 45° angle was chosen to minimize the effect of angular error, and, although it was recognized that a substantial component of diffuse reflectance would be included in the observations, it was anticipated that the diffuse component would be relatively constant and could be accounted for in correlations with the Hunter instrument.

B. Construction

A Photovolt 90° reflectance head, without the photocell retaining collar, was mounted onto a rectangular box at an angle of 45° with the horizontal, as shown in Figure 17. A small window was cut in the foot of the device to coincide with the center of the light beam at 45°. The light returning to the photocell has a relatively large average divergence with the incidence beam, 6.9°. This divergence, although undesirable, is tolerable. The entire inside was painted flat black, and the foot of the device was rimmed with a 1/8 inch strip of sponge rubber to seal out extraneous light.

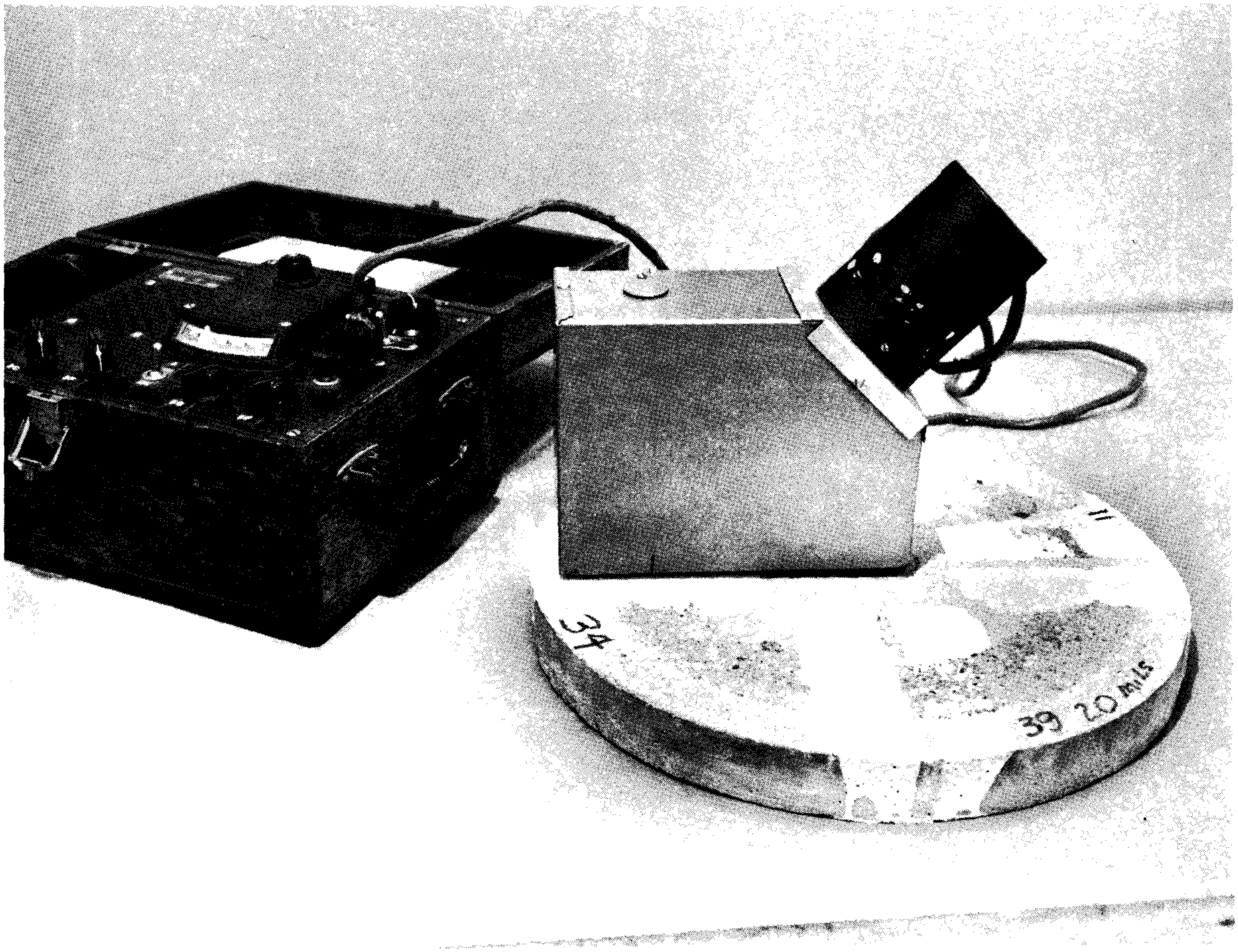

Figure 17. Special Night Visibility Meter.

C. Procedure for Use

The above described search head was used with the Photovolt Galvanometer Indicator Unit; calibration standards and procedures were identical to those of the Hunter instrument.

D. Correlation

Since the Hunter Night Visibility Meter has been used extensively in highway testing programs, including ours, a correlation curve was prepared as shown in Figure 18. This curve represents a least squares correlation of identical field observations with each instrument. Individual data points are not shown on the plot, but a moderate scattering about the least squares line was observed, as expected, in view of the geometrical dissimilarities of the instruments. The precision of the correlation was considered to be entirely adequate for requirements of the project work.

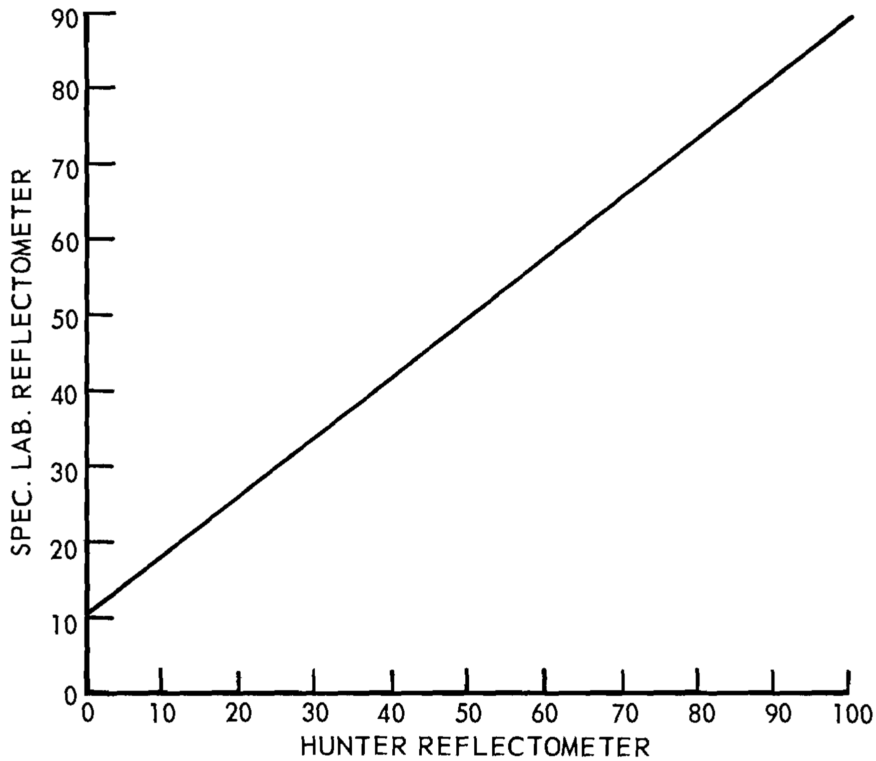

Figure 18. Correlation of Hunter and Special N.V. Meters.

D. Accelerated Wear Test Data

TABLE XI

ACCELERATED WEAR TEST DATA

Paint No.																	
		Disc No. 82				Operating Condition III						Substrate - Concrete					
90	Test Hrs.	1.3	1.8	2.3	3.3	4.4	5.3	6.5	8.9	12.3	15.3	24.1	33.7	42.7	65.5	87.4	103.8
	Integr. Night Vis.	8	8	8	8	8	8	8	7	7	7	7	7	7	7	7	7
	Test Hrs.	112.8	129.2	136.6	152.8	159.8	176.2	208.3	228.1	251.7	278.8	297.0	326.7	351.8	354.8		
	Integr. Night Vis.	7	7	7	7	7	7	7	6	6	6	6	6	6	6		
84	Test Hrs.	1.3	1.8	2.3	3.3	4.4	5.3	6.5	8.9	12.3	15.3	24.1	33.7	42.7	65.5	87.4	103.8
	Integr. Night Vis.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	Test Hrs.	112.8	129.2	136.6	152.8	159.8	176.2	208.3	228.1	251.7	278.8	297.0	326.7	351.8	354.8		
	Integr. Night Vis.	10	10	10	10	10	10	10	10	10	10	10	10	10	10		
88	Test Hrs.	1.3	1.8	2.3	3.3	4.4	5.3	6.5	8.9	12.3	15.3	24.1	33.7	42.7	65.5	87.4	103.8
	Integr. Night Vis.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	Test Hrs.	112.8	129.2	136.6	152.8	159.8	176.2	208.3	228.1	251.7	278.8	297.0	326.7	351.8	354.8		
	Integr. Night Vis.	10	10	10	10	10	10	10	10	10	10	10	10	10	10		
86	Test Hrs.	1.3	1.8	2.3	3.3	4.4	5.3	6.5	8.9	12.3	15.3	24.1	33.7	42.7	65.5	87.4	103.8
	Integr. Night Vis.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	Test Hrs.	112.8	129.2	136.6	152.8	159.8	176.2	208.3	228.1	251.7	278.8	297.0	326.7	351.8	354.8		
	Integr. Night Vis.	10	10	10	10	10	10	10	10	10	10	10	10	10	10		

(Continued)

TABLE XI (Continued)

Disc No. 83 — **Operating Condition II** — **Substrate - Concrete**

Paint No.													
90	Test Hrs.	0.4	1.0	2.0	5.3	6.4	7.0	8.4	10.4	13.1	14.9	16.4	20.4
	Integr.	10	9	8	7	6	6	5	4	4	4	4	3
	Night Vis.	21	20	18	20		19	18	17	14	16	17	15
84	Test Hrs.	0.4	1.0	2.0	5.3	6.4	7.0	8.4	10.4	13.1	14.9	16.4	20.4
	Integr.	10	10	9	9	8	8	8	7	6	5	4	4
	Night Vis.	22	22	21	20		18	18	19	16	18	16	16
88	Test Hrs.	0.4	1.0	2.0	5.3	6.4	7.0	8.4	10.4	13.1	14.9	16.4	20.4
	Integr.	10	10	10	9	7	7	7	6	5	5	5	4
	Night Vis.	22	22	21	20		14	15	17	16	15	14	15
86	Test Hrs.	0.4	1.0	2.0	5.3	6.4	7.0	8.4	10.4	13.1	14.9	16.4	20.4
	Integr.	10	10	8	7	7	7	6	5	4	4	4	3
	Night Vis.	22	22	21	20		18	16	17	14	16	15	15

Disc. No. 84 — **Operating Condition II** — **Substrate - Concrete**

Paint No.											
90	Test Hrs.	0.5	1.0	2.0	3.0	4.0	5.2	7.5	8.0	9.4	12.0
	Integr.	9	8	6	6	4	4	4	4	3	2
	Night Vis.	23	20	12	13	12	12	12	10	12	12
84	Test Hrs.	0.5	1.0	2.0	3.0	4.0	5.2	7.5	8.0	9.4	12.0
	Integr.	10	10	9	9	9	9	8	8	7	5
	Night Vis.	21	20	18	19	18	18	18	17	17	16
88	Test Hrs.	0.5	1.0	2.0	3.0	4.0	5.2	7.5	8.0	9.4	12.0
	Integr.	10	9	8	8	7	6	5	5	4	3
	Night Vis.	21	20	18	18	16	16	16	16	16	16

(Continued)

TABLE XI (Continued)

Paint No.											
	Disc No. 84 (cont.)			Operating Condition II					Substrate - Concrete		
86	Test Hrs.	0.5	1.0	2.0	3.0	4.0	5.2	7.5	8.0	9.4	12.0
	Integr.	10	10	10	10	9	8	7	7	5	5
	Night Vis.	23	20	19	18	16	17	18	17	17	16
	Disc No. 85			Operating Condition II					Substrate - Concrete		
90	Test Hrs.	0.5	1.0	1.5	3.5						
	Integr.	9	7	5	4						
	Night Vis.	18	16		15						
84	Test Hrs.	0.5	1.0	1.5	3.5						
	Integr.	10	8	7	4						
	Night Vis.	19	19		15						
88	Test Hrs.	0.5	1.0	1.5	3.5						
	Integr.	10	9	8	4						
	Night Vis.	20	19		14						
86	Test Hrs.	0.5	1.0	1.5	3.5						
	Integr.	10	9	8	4						
	Night Vis.	19	19		16						
	Disc No. 86			Operating Condition III					Substrate - Concrete		
90	Test Hrs.	0.6	1.4	1.7	2.9	28.5	72.1	81.0	101.7	119.5	
	Integr.	9	7	5	4	4	4	4	4	4	
	Night Vis.										
84	Test Hrs.	0.6	1.4	1.7	2.9	28.5	72.1	81.0	101.7	119.5	
	Integr.	10	10	10	10	10	10	10	9	9	
	Night Vis.										

(Continued)

TABLE XI (Continued)

Paint No.													
	Disc No. 86 (cont.)			Operating Condition III				Substrate - Concrete					
88	Test Hrs.	0.6	1.4	1.7	2.9	28.5	72.1	81.0	101.7	119.5			
	Integr.	10	10	10	10	10	10	9	9	9			
	Night Vis.												
86	Test Hrs.	0.6	1.4	1.7	2.9	28.5	72.1	81.0	101.7	119.5			
	Integr.	10	10	10	10	10	10	10	9	9			
	Night Vis.												
	Disc No. 87			Operating Condition III				Substrate - Concrete					
90	Test Hrs.	3.0	6.2	30.5	49.2								
	Integr.	7	7	7	6								
	Night Vis.												
84	Test Hrs.	3.0	6.2	30.5	49.2								
	Integr.	10	10	10	10								
	Night Vis.												
88	Test Hrs.	3.0	6.2	30.5	49.2								
	Integr.	10	10	9	9								
	Night Vis.												
86	Test Hrs.	3.0	6.2	30.5	49.2								
	Integr.	10	10	9	9								
	Night Vis.												
	Disc No. 94			Operating Condition VI				Substrate - Concrete					
90	Test Hrs.	1.0	1.5	2.5	2.9	4.0	5.1	6.4	7.8	9.6	10.5	12.5	13.3
	Integr.	10	8	8	7	6	5	4	4	4	4	4	3
	Night Vis.	20	18		18	18	17				17		18

(Continued)

TABLE XI (Continued)

Disc No. 94 (cont.) Operating Condition VI Substrate - Concrete

Paint No.													
84	Test Hrs.	1.0	1.5	2.5	2.9	4.0	5.1	6.4	7.8	9.6	10.5	12.5	13.3
	Integr.	10	10	10	10	9	9	8	7	6	6	5	4
	Night Vis.	20	20		20	20	20				18		15
88	Test Hrs.	1.0	1.5	2.5	2.9	4.0	5.1	6.4	7.8	9.6	10.5	12.5	13.3
	Integr.	10	10	9	9	8	8	6	6	5	5	4	3
	Night Vis.	19	19		19	20	18				16		18
86	Test Hrs.	1.0	1.5	2.5	2.9	4.0	5.1	6.4	7.8	9.6	10.5	12.5	13.3
	Integr.	10	10	10	10	9	8	7	7	6	6	5	4
	Night Vis.	20	20		20	20	20				18		15

Disc No. 96 Operating Condition VI Substrate - Concrete

Paint No.																
90	Test Hrs.	1.1	2.3	3.7	5.1	7.2	8.6	11.6	12.6	15.1	17.9	19.1	21.6	25.1	27.2	30.3
	Integr.	10	8	7	7	6	5	4	4	4	3	3	3	3	3	3
	Night Vis.	21	20		18	20		17		17	15			14		14
84	Test Hrs.	1.1	2.3	3.7	5.1	7.2	8.6	11.6	12.6	15.1	17.9	19.1	21.6	25.1	27.2	30.3
	Integr.	10	10	10	9	8	8	7	7	7	6	6	6	6	5	5
	Night Vis.	21	21		20	20		20		20	19			18		18
88	Test Hrs.	1.1	2.3	3.7	5.1	7.2	8.6	11.6	12.6	15.1	17.9	19.1	21.6	25.1	27.2	30.3
	Integr.	10	10	10	9	8	8	7	7	7	6	5	5	5	4	4
	Night Vis.	22	21		20	20		19		19	16			14		
86	Test Hrs.	1.1	2.3	3.7	5.1	7.2	8.6	11.6	12.6	15.1	17.9	19.1	21.6	25.1	27.2	30.3
	Integr.	10	10	10	10	9	9	8	7	6	6	6	5	5	5	4
	Night Vis.	25	21		21	21		18		19	18			18		18

(Continued)

TABLE XI (Continued)

Paint No.																
	Disc No. 98				Operating Condition VI					Substrate - Concrete						
90	Test Hrs.	2.9	4.2	6.7	8.5	11.0	12.0	14.1	15.0	18.0	19.4	23.1	25.0	27.0	29.1	30.4
	Integr.	9	8	7	7	7	7	6	5	5	5	4	4	4	3	3
	Night Vis.		20		17	17				16						15
84	Test Hrs.	2.9	4.2	6.7	8.5	11.0	12.0	14.1	15.0	18.0	19.4	23.1	25.0	27.0	29.1	30.4
	Integr.	10	10	9	9	9	9	8	7	7	7	6	6	5	4	4
	Night Vis.		20		18	18				18						18
88	Test Hrs.	2.9	4.2	6.7	8.5	11.0	12.0	14.1	15.0	18.0	19.4	23.1	25.0	27.0	29.1	30.4
	Integr.	10	9	8	8	8	8	7	7	7	7	6	6	6	5	5
	Night Vis.		20		18	18				17						17
86	Test Hrs.	2.9	4.2	6.7	8.5	11.0	12.0	14.1	15.0	18.0	19.4	23.1	25.0	27.0	29.1	30.4
	Integr.	10	9	8	8	8	8	7	7	7	7	5	5	5	4	4
	Night Vis.															
	Disc No. 103*				Operating Condition V					Substrate - Concrete, Waxed						
90	Test Hrs.	0.2														
	Integr.	1														
	Night Vis.															
84	Test Hrs.	0.2														
	Integr.	1														
	Night Vis.															
88	Test Hrs.	0.2														
	Integr.	2														
	Night Vis.															

*Because of the unexpected exceedingly rapid deterioration of all the films, no intermittent readings were obtained.

(Continued)

TABLE XI (Continued)

Paint No.															
	Disc No. 103* (cont.)				Operating Condition V					Substrate - Concrete, Waxed					
86	Test Hrs.	0.2													
	Integr. Night Vis.	1													
	Disc No. 104				Operating Condition V					Substrate - Concrete, Waxed					
90	Test Hrs.	0.1	0.3	1.6	2.9	3.7	4.7	6.2	7.5	8.3	9.2	10.3	12.8	15.0	20.0
	Integr. Night Vis.	8	7	7	6	6	6	6	5	5	5	5	4	3	3
	Test Hrs.	22.2	23.1	26.8											
	Integr. Night Vis.	2	2	2											
84	Test Hrs.	0.1	0.3	1.6	2.9	3.7	4.7	6.2	7.5	8.3	9.2	10.3	12.8	15.0	20.0
	Integr. Night Vis.	10	10	10	9	9	9	9	9	9	9	9	9	9	9
	Test Hrs.	22.2	23.1	26.8											
	Integr. Night Vis.	9	9	9											
88	Test Hrs.	0.1	0.3	1.6	2.9	3.7	4.7	6.2	7.5	8.3	9.2	10.3	12.8	15.0	20.0
	Integr. Night Vis.	10	10	9	7	6	6	6	6	6	6	6	5	5	5
	Test Hrs.	22.2	23.1	26.8											
	Integr. Night Vis.	5	4	4											

*Because of the unexpected exceedingly rapid deterioration of all the films, no intermittent readings were obtained.

(Continued)

TABLE XI (Continued)

Paint No.

Disc No. 104 (cont.) — Operating Condition V — Substrate - Concrete, Waxed

Paint No.															
86	Test Hrs.	0.1	0.3	1.6	2.9	3.7	4.7	6.2	7.5	8.3	9.2	10.3	12.8	15.0	20.0
	Integr. Night Vis.	10	8	5	4	2	2	2	1	1	1	1	1	1	1
	Test Hrs.	22.2	23.1	26.8											
	Integr. Night Vis.	1	1	1											

Disc No. 105 — Operating Condition V — Substrate - Concrete, Waxed

Paint No.												
90	Test Hrs.	0.3	1.3	2.5	3.8	7.5	9.1	10.1	13.7	15.9	18.7	22.7
	Integr. Night Vis.	8	7	7	7	6	6	5	5	5	5	5
84	Test Hrs.	0.3	1.3	2.5	3.8	7.5	9.1	10.1	13.7	15.9	18.7	22.7
	Integr. Night Vis.	10	10	9	9	9	9	9	9	9	9	9
88	Test Hrs.	0.3	1.3	2.5	3.8	7.5	9.1	10.1	13.7	15.9	18.7	22.7
	Integr. Night Vis.	10	8	5	5	2	1	1	1	1	1	1
86	Test Hrs.	0.3	1.3	2.5	3.8	7.5	9.1	10.1	13.7	15.9	18.7	22.7
	Integr. Night Vis.	5	3	2	1	1	1	1	1	1	1	1

Disc No. 106 — Operating Condition V — Substrate - Transite

Paint No.																
90	Test Hrs.	0.5	1.5	3.2	9.1	15.3	19.4	26.0	39.5	46.7	61.7	66.1	69.4	84.2	91.2	110.8
	Integr. Night Vis.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

(Continued)

TABLE XI (Continued)

Paint No.																
	Disc No. 106 (cont.)				Operating Condition V						Substrate - Transite					
90	Test Hrs.	134.9	155.0	164.3	177.1	185.8	201.4	210.1								
	Integr. Night Vis.	10	10	10	10	10	10	10								
84	Test Hrs.	0.5	1.5	3.2	9.1	15.3	19.4	26.0	39.5	46.7	61.7	66.1	69.4	84.2	91.2	110.8
	Integr. Night Vis.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	Test Hrs.	134.9	155.0	164.3	177.1	185.8	201.4	210.1								
	Integr. Night Vis.	10	10	10	10	10	10	10								
88	Test Hrs.	0.5	1.5	3.2	9.1	15.3	19.4	26.0	39.5	46.7	61.7	66.1	69.4	84.2	91.2	110.8
	Integr. Night Vis.	10	10	10	8	8	8	8	8	8	8	8	8	8	8	8
	Test Hrs.	134.9	155.0	164.3	177.1	185.8	201.4	210.1								
	Integr. Night Vis.	8	8	8	8	8	8	8								
86	Test Hrs.	0.5	1.5	3.2	9.1	15.3	19.4	26.0	39.5	46.7	61.7	66.1	69.4	84.2	91.2	110.8
	Integr. Night Vis.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	Test Hrs.	134.9	155.0	164.3	177.1	185.8	201.4	210.1								
	Integr. Night Vis.	9	9	9	9	9	9	9								
	Disc No. 107				Operating Condition V						Substrate - Polished Glass					
90	Test Hrs.	0.1	0.3	0.7	1.1	2.7	4.4	9.1								
	Integr. Night Vis.	8	7	3	2	1	1	1								

(Continued)

TABLE XI (Continued)

Paint No.												
	Disc No. 107 (cont.)				Operating Condition V						Substrate - Polished Glass	
84	Test Hrs.	0.1	0.3	0.7	1.1	2.7	4.4	9.1				
	Integr. Night Vis.	10	10	10	10	9	8	5				
88	Test Hrs.	0.1	0.3	0.7	1.1	2.7	4.4	9.1				
	Integr. Night Vis.	10	10	10	10	8	6	5				
86	Test Hrs.	0.1	0.3	0.7	1.1	2.7	4.4	9.1				
	Integr. Night Vis.	10	10	10	10	10	10	10				
	Disc No. 110				Operating Condition V						Substrate - Transite, Waxed	
90	Test Hrs.	0.2	0.8	1.3	3.2	4.1	6.7	9.3	11.5	18.0	19.7	26.4
	Integr. Night Vis.	10	6	5	5	2	2	1	1	1	1	1
84	Test Hrs.	0.2	0.8	1.3	3.2	4.1	6.7	9.3	11.5	18.0	19.7	26.4
	Integr. Night Vis.	10	10	10	2	1	1	1	1	1	1	1
88	Test Hrs.	0.2	0.8	1.3	3.2	4.1	6.7	9.3	11.5	18.0	19.7	26.4
	Integr. Night Vis.	10	4	2	1	1	1	1	1	1	1	1
86	Test Hrs.	0.2	0.8	1.3	3.2	4.1	6.7	9.3	11.5	18.0	19.7	26.4
	Integr. Night Vis.	10	6	5	4	2	2	2	2	1	1	1

(Continued)

TABLE XI (Continued)

Disc No. 111 — Operating Condition V — Substrate - Ground Glass

Paint No.								
90	Test Hrs.	0.3	2.5	3.9	6.9	11.7	13.5	16.1
	Integr.	4	1	1	1	1	1	1
	Night Vis.							
84	Test Hrs.	0.3	2.5	3.9	6.9	11.7	13.5	16.1
	Integr.	10	9	9	9	9	9	9
	Night Vis.							
88	Test Hrs.	0.3	2.5	3.9	6.9	11.7	13.5	16.1
	Integr.	10	9	7	7	5	5	5
	Night Vis.							
86	Test Hrs.	0.3	2.5	3.9	6.9	11.7	13.5	16.1
	Integr.	9	9	8	8	8	8	8
	Night Vis.							

Disc No. 112 — Operating Condition V — Substrate - Ground Glass, Waxed

Paint No.													
90	Test Hrs.	0.2	1.6	2.9	4.1	5.0	6.0	7.9	10.6	12.3	15.6	19.7	21.0
	Integr.	9	5	4	3	2	2	2	2	2	1	1	1
	Night Vis.												
84	Test Hrs.	0.2	1.6	2.9	4.1	5.0	6.0	7.9	10.6	12.3	15.6	19.7	21.0
	Integr.	10	10	10	10	10	10	10	10	10	9	9	9
	Night Vis.												
88	Test Hrs.	0.2	1.6	2.9	4.1	5.0	6.0	7.9	10.6	12.3	15.6	19.7	21.0
	Integr.	10	10	10	9	9	9	9	9	9	9	9	9
	Night Vis.												

(Continued)

TABLE XI (Concluded)

Paint No.													
		Disc No. 112 (cont.)			Operating Condition V					Substrate - Ground Glass, Waxed			
86	Test Hrs.	0.2	1.6	2.9	4.1	5.0	6.0	7.9	10.6	12.3	15.6	19.7	21.0
	Integr.	10	10	10	10	10	10	10	10	10	9	9	9
	Night Vis.												
		Disc No. 113			Operating Condition V					Substrate - Polished Glass, Waxed			
90	Test Hrs.	0.5	1.0	2.1	3.0	4.5	6.4	7.4	8.4	9.9			
	Integr.	6	5	2	2	1	1	1	1	1			
	Night Vis.												
84	Test Hrs.	0.5	1.0	2.1	3.0	4.5	6.4	7.4	8.4	9.9			
	Integr.	10	10	9	8	7	7	7	7	5			
	Night Vis.												
88	Test Hrs.	0.5	1.0	2.1	3.0	4.5	6.4	7.4	8.4	9.9			
	Integr.	9	9	7	6	5	4	2	2	2			
	Night Vis.												
86	Test Hrs.	0.5	1.0	2.1	3.0	4.5	6.4	7.4	8.4	9.9			
	Integr.	10	10	10	10	10	9	9	9	8			
	Night Vis.												

E. Film Characterization Test Methods

A. Panel Preparation

1. All tests were performed on cold-rolled steel panels, ASTM Designation A-109, Rockwell hardness 55 to 65, satin finish, 3 inches wide by 6 inches long by 1/32 inch thick.

2. Panels were solvent-cleaned with a mixture of toluene and mineral spirits and allowed to air-dry.

3. Paints were applied with a Baker blade to obtain a uniform coating over each panel. A maximum (10 mil) setting was used on the blade for all paints. Dry film thicknesses ranged from 2 to 4 mils.

4. All panels were allowed to air-dry in the laboratory for seven days prior to testing.

5. After the seven days' air drying period, panels designated for accelerated heat ageing were placed in an oven at 80° C for a period of 24 hours. Thereafter, they were removed and allowed to return to room temperature prior to testing.

B. Description of Test Methods

1. Conical Mandrel Flexibility Test

(a) The test was performed as specified in ASTM D 522-60, except that: (1) panels were 3 inches wide by 6 inches long, rather than $4\frac{1}{2}$ by $7\frac{1}{2}$ inches; (2) cracks were examined under a microscope rather than with the unaided eye; and (3) the end point of cracking failure was defined as the end of the last continuous crack visible with a microscope, rather than simply the last visible crack.

(b) The essential elements of the test are: (1) The panel is clamped in the apparatus, lubricated with talc, and protected from the bending roller with kraft paper. (2) The panel is bent around the conical steel mandrel through an angle of almost 180° in about 15 seconds. (3) The panel is examined for cracking immediately. (4) Humidity and temperature must be consistent for all tests.

Percentage elongation of the film is related to radius of bending at the end point by a graph which is a part of the ASTM method description.

2. Pencil Hardness Test

Pencil hardness is a fairly well known technique 5/, although it has not been adopted as standard by any organization. Essential elements of the test are: (1) the lead is squared off by sanding the end flat, perpendicular to the length of the pencil; the lead is then ground to a rectangular cross-section, so that four sharp 90° corners are available for the test; (2) the same brand of pencil must be used for all tests, if results are to be comparable; (3) the pencil is held in the normal writing position, about 45°, and pushed against the film. If the point crumbles without marring the film, the next harder grade is tried, until a grade is found which does mar the film. Hardness is recorded as the hardest grade which fails to mar the film.

3. Angular Scribe-Stripping (Adherence Number) Test

The Adherence Number Test is performed with the Paint Inspection Gage 9/. The instrument consists of two functional parts: (1) a tungsten carbide cutting tip and a guide stud assembly which causes the tip to slice through the paint film at a precise angle from the horizontal (arc tan 0.1) and (2) a 50 power microscope fitted with a reticle calibrated in mils, which is used to measure dimensions of the cut.

The shearing action of the tip causes a strip of paint to separate from the substrate at the edge of the cut, as shown in Figure 19. The

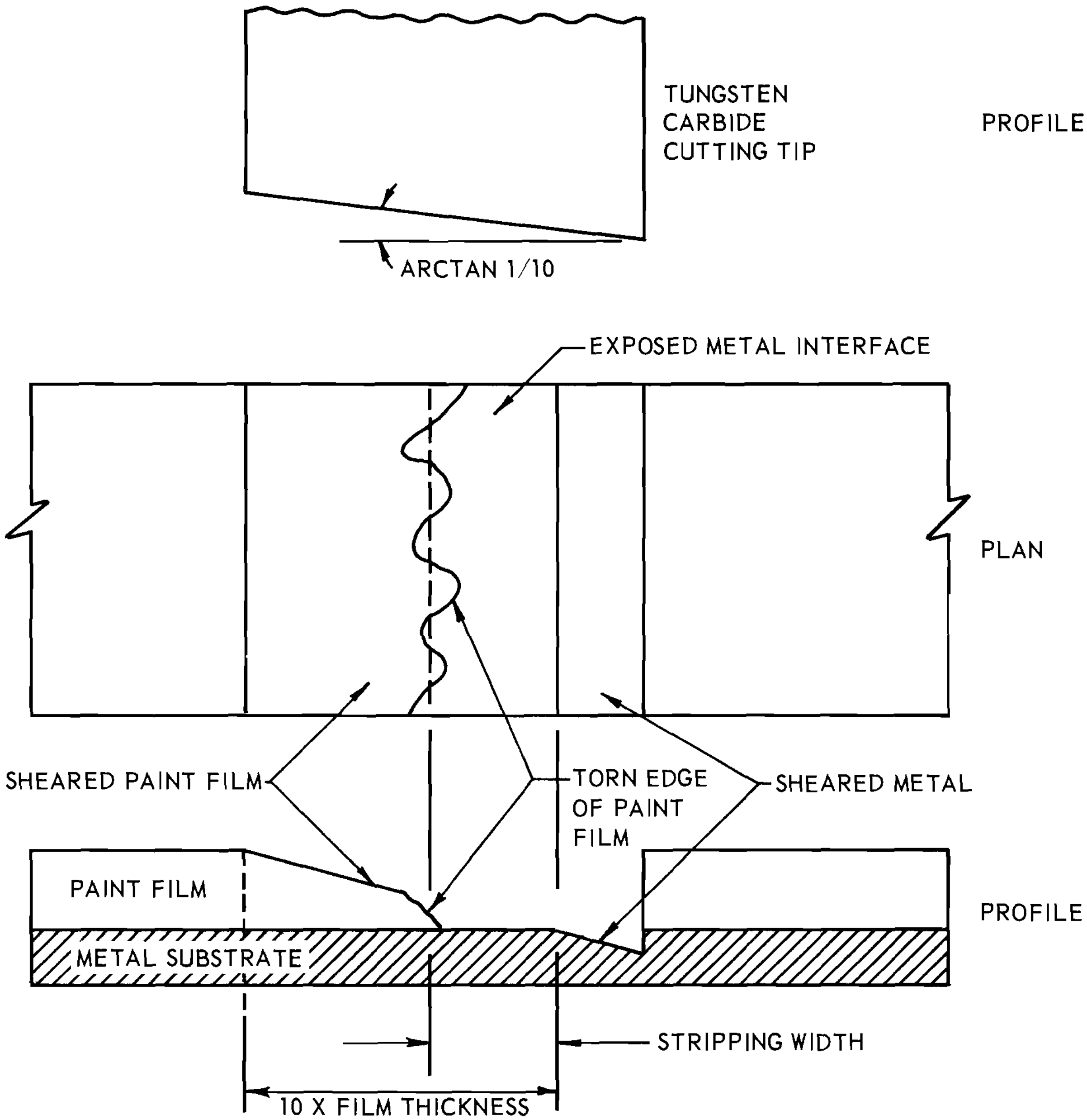

Figure 19. Scribe Made with Paint Inspection Gage Showing Stripping Width.

mean width of the strip of exposed interface (stripping width) is measured with the microscope. Film thickness is also measured with the Paint Inspection Gage. From these two measurements, adherence of the film can be expressed:

$$\text{Adherence Number} = \frac{\text{Film Thickness (mils)}}{\text{Stripping Width (mils)}} \times 10$$

Paint systems with good adhesion exhibit higher adherence numbers. The adherence number is independent of film thickness.

4. Reverse Impact Test

The reverse impact test (like the pencil hardness test) is a well known technique, although it has not been adopted as standard by any organization. The Gardner Impact Tester is used for the test 10/.

A spherical-nosed weight is dropped through a tube upon the reverse side of a coated panel. The lowest impact (inch-pounds) which produces cracking on the coating is recorded.

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